

The Beginnings of Stealth Technology

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This paper focuses on work led by the Air Force Avionics Laboratory from the early 1950s to 1970, emphasizing radar echo, although all observables—infrared radiation, optical, acoustic, etc.—are important to “stealth” design. It traces the current capability to minimize observables from the first efforts to understand what determines radar echo, through the development of materials and techniques to minimize it, to its’ first applications and demonstrations.

Traditionally Pioneer Awardees are afforded the opportunity to share some of the events surrounding their work with the attendees at NAECON and, through these pages, with all readers. It also affords future historians an opportunity to “listen” to the personal comments of the authors.

Manuscript received May 6, 1993.

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1993 PIONEER AWARD: BAHRET

To put the following discussion into context, it is well to make several points at the outset. The first is to note that the title is presumptuous, in that nature understood stealth and evolved countless creatures whose survival depended on blending with the background long before “homo sapiens” figured it out. Thus, we will merely recite how the basic idea was applied to U.S. military systems in the last forty years or so.

Another point that must be made is on the limitations under which this document had to be written. Ordinarily, as military technology matures, any security imposed in the early stages to protect an advantage over an adversary, is slowly eroded as the information has to be shared to insure its application. However, the stealth community, like those associated with technologies for global reconnaissance and nuclear weapons for instance, elected to keep the state-of-the-art under wraps. To be sure, the media has gone to great pains to locate sources with decent credentials who are willing to speculate on how the stealth capability is accomplished. This leads the interested-but-outside-the-fence reader to conclude that everything is out in the open. We will leave it at that, but will say for the record that this article is limited in content by security considerations.

A third point is that, while this article will discuss stealth in the radar spectrum, it must be noted that any “observable”—infrared, visible, acoustic.—is of concern. Space and time simply prohibit any presentation on the breadth of this technology. In modern times, the radar signature is the first order problem anyway.

The final point of orientation relates to the idea of “blending with the background” as it applies to military systems. We are all well aware of examples in nature—the new-born fawn laying silently in the brush, or the poisonous snake wrapped around a leafy limb—whose coloration and shape make them virtually undetectable at any distance by their normal enemies or prey. These are effective because there is a lack of contrast so needed for ordinary detection.

Keep in mind however, that contrast can be positive or negative—the full moon against the night sky versus the black panther on snow. Either is bad if one is trying to avoid detection. So it is with military systems. The ship in rough sea or the tank in foliage would be badly served by having no “signature” at all for an opponent radar to see. The radar background is not zero in these cases!

However, the airborne vehicle is another matter. In the normal situation, the background seen by a hostile radar is essentially zero, so ideally, the vehicle should have a zero signature too. This of course is impractical if not impossible. The question then comes down to how small a signature should be sought. Realizing that “there is no free lunch”, one has to address the “cost effectiveness” of different amounts of reduction.

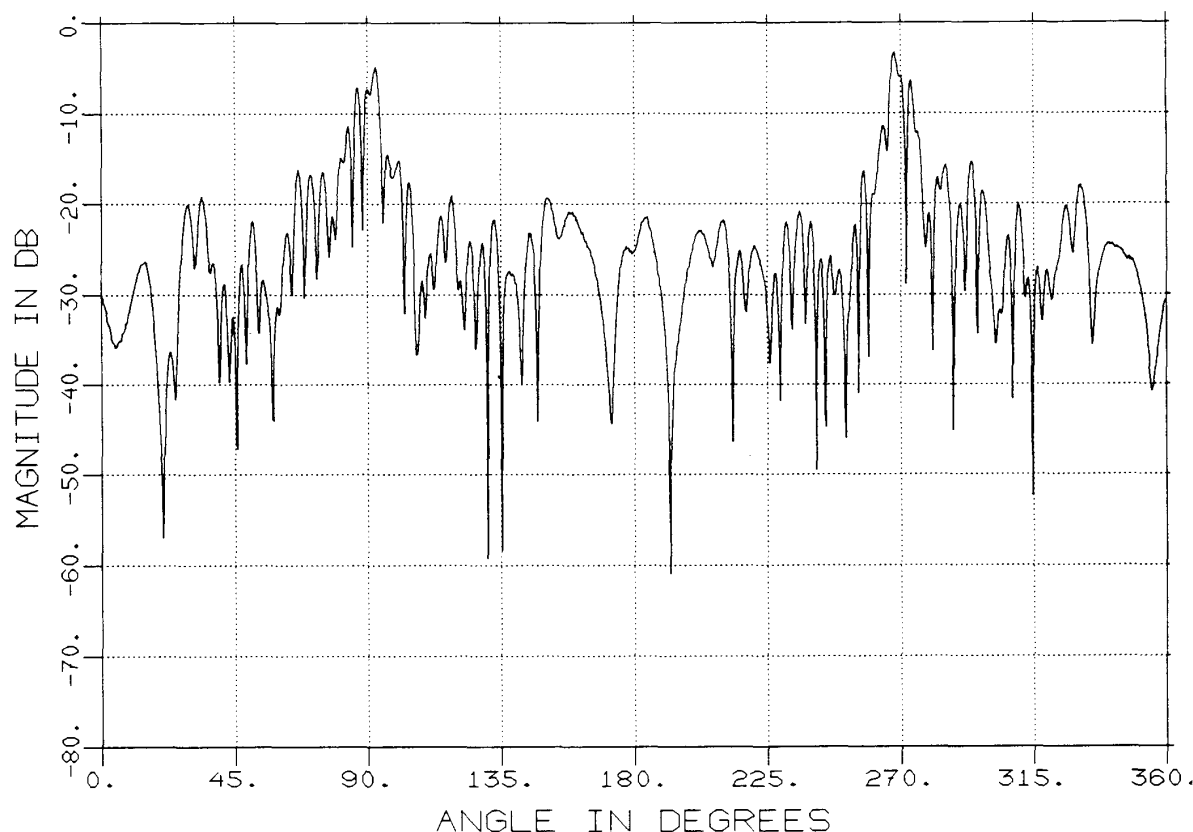


Fig. 1. Radar Cross Section (RCS) pattern.

Unfortunately, the way conventional radar works comes into the question.

A beam of energy radiated from an antenna spreads as it travels, and so does that portion of it that reflects from a target, all of which means that the energy density continuously decreases in both directions. The upshot of all this is that for a given size target, the amount of energy arriving back at the radar antenna is *inversely proportional to target range raised to the fourth power!* This assumes that the radar detection range is only limited by the system noise, but that is usually the case.

If one does the arithmetic connected with the relationship stated above, it becomes clear that to really hurt a hostile radar, one has to do heroic things in reducing a friendly vehicles signature. In simple English, it takes a 95% reduction in signature to reduce a radars' detection range by 50%, and a 99% reduction in signature to reduce the range by 67%. There is much more to this question of how much reduction is "cost effective," but exploring all this is not the purpose of this paper.

To get to the topic of interest here—reduction of radar signature (stealth as the media calls it)—we must say a few things so that the reader not in the business can follow the discussion. Fig. 1 shows a

typical pattern of the radar echo from an aircraft. This pattern was obtained by setting a precision model on a support, as if it was in level flight, then recording the echo amplitude while the model is rotated so that it is viewed from the nose to the tail and back to the nose again. (0° presents nose-on.) Such patterns are the basis for all analysis of radar echo, as well as determining the ability of the aircraft to penetrate a hostile defense. When properly calibrated, this pattern presents what is called the radar cross section (RCS) of the aircraft, as a function of viewing angle. Note that, for security reasons, amplitude for this sample pattern is presented only on a relative basis.

Neither time nor space will permit any complete presentation on all that this simple pattern provides in the way of information on the target. However, to appreciate what is of interest in the reduction of radar echo, let us make a few points about this pattern.

First, one sees an echo level which varies wildly. The fact is that this pattern was taken for a relatively low radar frequency, and had a much higher one been used, the lobe structure would have been so dense as to make the pattern almost a black blur.

The ordinate is plotted on a logarithmic scale (of necessity), because the actual amplitude varies over several orders of magnitude in fractions of a degree of

rotation. For those unfamiliar with a "log" scale, the major divisions on the ordinate each represent order of magnitude changes—0 to 10, 10 to 100, etc. One sees then, that in say a ten degree span, the amplitude often varies by 1000 to 1 and more.

Now this wild "lobe structure" is due to the echoes from different objects on the aircraft alternately reinforcing and cancelling each other as their relative positions change during the rotation of the aircraft. The same thing would happen if the aircraft was moved in the roll or pitch planes.

On top of this interference when the echo sources are rigidly fixed on a rotating body, we have the added motion of one source with respect to another due to turbulence in real-world flight (wings flapping, for instance). Hence this detailed pattern gets even wilder.

The point in all this is that the lobe structure is wonderfully interesting, but it is about as useful as air brakes on a turtle when it comes to worrying about a radar detecting the aircraft. The really important pattern is the one that can easily be seen as a much smoother line running through the very complex plot. This line is determined by statistics in practice, but exactly how this is done is not important here. Let us note however, that signature reduction (stealth) in the radar part of the spectrum requires the lowering of the smoothed pattern, although the amplitude of the lobes will naturally follow.

Now the fact that RCS was critical to determining radar performance was well known to radar designers and users in WWII. The sticky point that carried over long afterwards was the matter of determining this elusive parameter on an accurate basis. In the early 1950s, a research thrust, in the predecessor organization to the Avionics Laboratory at Wright-Patterson Air Force Base, was the exploration of methods for doing this. This was when the author was assigned to the team.

By then, it was known that the RCS of an aircraft was not only as complex in angle as just discussed, but was also a function of the configuration of the vehicle, as well as the illuminating radar frequency and polarization. It began to look like one working on this would have guaranteed employment for a long time, even if only one aircraft was involved.

There were three methods potentially available for characterizing RCS: 1) Dynamic measurement (measuring RCS while the aircraft flew), 2) Calculation, and 3) Model measurement. Each had good news and bad news, to no surprise.

Dynamic measurements involved instrumenting and calibrating a radar, usually on the ground, then keeping it aimed at the subject aircraft while it flew precision patterns designed to present a variety of "aspect angles" to the radar. This was a fine way to measure RCS because one did not have to know a thing about the underlying factors that went to produce the echo. One merely recorded the result of whatever

the sources were and went away with the feeling of accomplishment.

Of course, there were a few drawbacks. The first, and most obvious, was that you had to have the aircraft of interest designed, built, and ready to fly. Doing anything about gleam-in-the-eye designs was out of the question. Then there is the small matter of knowing the aspect angle to which an RCS data point corresponded, and further, of even getting the range of angles for which RCS data were needed.

Without doing a heroic job of instrumenting the test aircraft (hardly conducive to either inexpensive testing or cataloging a wide variety of vehicles), there was only crude knowledge of aspect angle, and that is not what one needs in light of Fig. 1. Furthermore, if one is on the ground looking up at a test aircraft, needing a certain minimum range to obtain good data, it is easy to see how the available aspect angles would be severely restricted, even if the pilot was a dare-devil. For all these reasons, dynamic measurement has been relegated to the "proof-of-the-pudding" testing after designs are finally built.

Calculations were possibilities, but in the early days, the algorithms were scarcely up to predicting the RCS of even a simple solid body such as a football shape. Doing anything as complex as an aircraft was out of the question (doing that in detail still is!), and even if the equations had been up to it, cranking them out on adding machines did not seem too promising. Only the advent of high-speed computers made doing RCS calculations possible at a later time.

This left model measurement as a promising approach. Now antenna people had used scaling techniques for a long time, and had proven the validity and accuracy. One simply scaled an aircraft by some factor, then scaled the illuminating wavelength by the same factor, and the measured antenna patterns came out just as if the full-scaled aircraft had been tested at the unscaled wavelength.

Unfortunately, the direct transition of this approach to RCS measurements had a few problems. By far the most critical was the matter of detail in the model. For most antenna pattern needs, only the gross geometry of the vehicle factors in. Early on however, it was found that modeling only the gross features led to completely erroneous RCS data. Several organizations engaged in either dynamic measurements, calculations, or model measurements, produced such conflicting data that skeptics doubted any possibility of cataloging RCS for all the aircraft at a wide variety of radar frequencies.

It was this problem alone that inspired efforts at Avionics Laboratory (we will use this name because it endured for most of the period under discussion) to investigate the needs for detail in a good RCS model, and results of that research were what led to interest in possibilities to control RCS. If one understood what influenced RCS, why not try to minimize it?

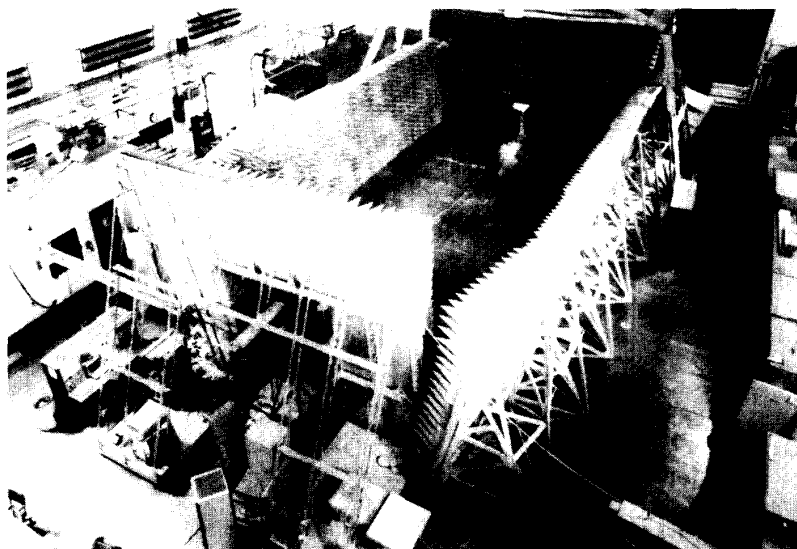


Fig. 2. RCS measurement range.

Of course, to do any such investigation, one needed a proper measurement facility. Fig. 2 shows one designed and built by this author and his team in a very large building at Wright-Patterson Air Force Base. Due to its' dominant influence on signature control technology for many years, this facility became known to all the members of the RCS community, and the unique building in which it was housed became known far and wide as "the barn", for its' shape.

Without belaboring all the complexities of such a facility, several requirements should be mentioned. Obviously, the facility had to be able to measure the signal reflected from a target in question, with negligible effects from the surroundings. This forced the design of an "anechoic" chamber which provided a background whose own echoes were many orders of magnitude below those of any target. Similarly, the support used to control the position of a target during measurement had to be such that its' echo was negligible compared to that from any target. Needless to say, much research had to be done by many people—absorber design for chamber walls, model support techniques, echo cancellation techniques etc.—to permit the design of the facility with the required capability, and the organizations that contributed to that are too numerous to mention here.

In addition, the instrumentation had to provide the range of frequencies and polarizations necessary to illuminate a target, and had to be well calibrated and stable enough to maintain the calibration all through a measurement. Like the advent of fire as seen by those who have been long accustomed to automatic heating and cooking devices, many readers may not appreciate the difficulties in achieving all this in the 50s. But those who shared in the early days know full

well how it was before phased-locked signal sources, off-the-shelf receivers with huge dynamic range and operating bandwidth, and other wonderful devices readily available today.

Having a means to do so, the investigation of what was important to a vehicles' echo began in earnest in the middle 50s. The method was simply cut-and-try, because there was no theoretical guidance to work from. Keep in mind that, even if the means to calculate RCS had been available, good results would have required the same thing that measurements did—the knowledge of how to make a good model!

This cut-and-try process involved spending a lot of time on one aircraft. Several models would be made with increasing amounts of detail (and cost) until the point of diminishing returns showed up in the measured data.

Sometimes, the enthusiasm of electromagnetics people, coupled with a total lack of knowledge of aerodynamic effects, led to strange results. We used to make the RCS test models of fiberglass over wooden frames, to keep the weight down. The whole was then painted with conductive metallic paint to provide the proper simulation of the normal metal surface. In one particular case, we were trying to see the effects of rotating propellers on the vehicles' echo pattern (the more youthful readers will have to refer to the archives to learn about prop-driven machines). We had a model of a C-47 made to one-eighth scale—a rather big model to be sure. We scaled the dimensions of every part of the aircraft, even to the propellers, and then we had electric motors installed in each engine to turn them at normal cruise RPM.

When we put this on the "low echo" support column, as soon as the motors were energized, the

whole thing flew forward and into the ground some distance below. Afterwards, some aero experts (where are they when you need them?) had great sport with how we had scaled the weight much more through the modeling process than we had the thrust of the engines. Nobody's perfect!

Besides varying the amount of detail in a model, we also tried an assortment of tricks to eliminate a suspected echo source (we called them flare spots) in order to observe how important it was. Depending on its' shape and location, we might cover it with metal foil, or, after it became available, with thin flexible radar absorber material.

The result of all this experimentation was a gradually increasing understanding of flare spots—what they were for different vehicles, how they behaved at different radar frequencies, and how they should be modeled. The picture emerged that the influence of a flare spot was related to its' geometry first of all, but also to its' dimensions measured in the wavelengths with which it was illuminated.

What this means in simple terms is that at what are called "microwave frequencies"—those above 2000 megahertz (mhz) or so—a normal aircraft's echo derives from a set of individual sources, while at much lower frequencies, the increasing tendency is for the entire aircraft to act like one big source—with only the general shape being a factor. At extremely low frequencies, even the shape loses influence and only the volume matters. As was the case previously in this paper, a full discussion of this one point might fill a volume, so the interested reader must seek further information elsewhere unfortunately.

Coincidentally, at about the time when the understanding of echo sources was becoming clearer, we started a program for development of a radar absorber material (RAM), and that was the first effort by the Air Force specifically intended for the reduction of radar signature. This start, in 1955, eventually grew into a program that led all the military services for several decades.

Again, security prevents any discussion of any of the many types of RAM that were investigated over the years. We can observe however, that people who have some acquaintance with absorbers made for use in anechoic chambers often question why RAM designed for use on operational vehicles—aircraft say—does not have the same wonderful performance. A moment of thoughtful meditation should answer that question for anyone. In an anechoic chamber, the designer has virtually no limit on thickness or weight, no stringent environmental requirements, and most important of all, no limits on shape.

The latter turns out to be the clue to making chamber materials that reduce the echo from a wall by five orders of magnitude (50 db or 100,000 times). If one does the simple calculation of the reflection from a flat surface of virtually the least reflective

material with self-supporting ability—polystyrene foam—one finds that this reflection is only four orders of magnitude (40 db) below an identical metal surface. Obviously, the only way that chamber RAM obtains its' performance, even though it is denser than styrofoam, is because one does not look at a flat surface. Most chamber materials have surfaces that are pyramidal.

Clearly, RAM for aircraft surfaces must be as thin as possible, weigh as little as possible, withstand stressing temperatures, pressures, and erosive environments, and generally be covered by materials to keep things together structurally. And oh yes—it must not disturb the smooth contours of the airframe. Nobody said that the job had to be easy, though!

Complicating the RAM development problem, besides the necessity of creating suitable theoretical analysis methods, was the lack of apparatus that could accurately characterize the electrical properties of candidate ingredients. As in the case of understanding basic RCS, the need to be able to measure actual materials forced the development of special instrumentation. For years, the one problem that most hindered RAM advancement was this inability to accurately determine the dielectric and magnetic properties of ingredients.

Work during WWII on measuring impedance of loads on transmission lines (the classic slotted-line standing wave method) was a starting point for characterizing RAM ingredients, but it was woefully short when it came to the extremely high reflections usually obtained from such materials. (Without a lengthy dissertation on this apparent contradiction, the reader will have to accept the fact that, while ensembles of ingredient materials yield good "absorber materials", individually they can have very high reflection coefficients!). Since the needs during early (WWII) development of impedance-measuring techniques only involved loads that pretty well matched the line impedance, concern about things like RAM ingredients was unnecessary. In any case, when we tried to measure small differences in material properties due to changes in chemical makeup, we were stopped cold.

With the help of some very smart instrumentation people at Sperry Research, a system that used an "impulse"—actually a burst of energy lasting in the order of picoseconds—was developed to obtain electrical property data over a very wide range of frequencies (roughly 400 to 16,000 megahertz in our case) in a matter of a few seconds. Fig. 3 shows the facility which housed this and other materials measurement equipment. The impulse technique obtained useful data not so much because it was inherently more accurate than the slotted line technique, but because it provided thousands more data points over the band of interest. Smoothing the measured data eliminated the random errors that confused the interpretation of sparse data points

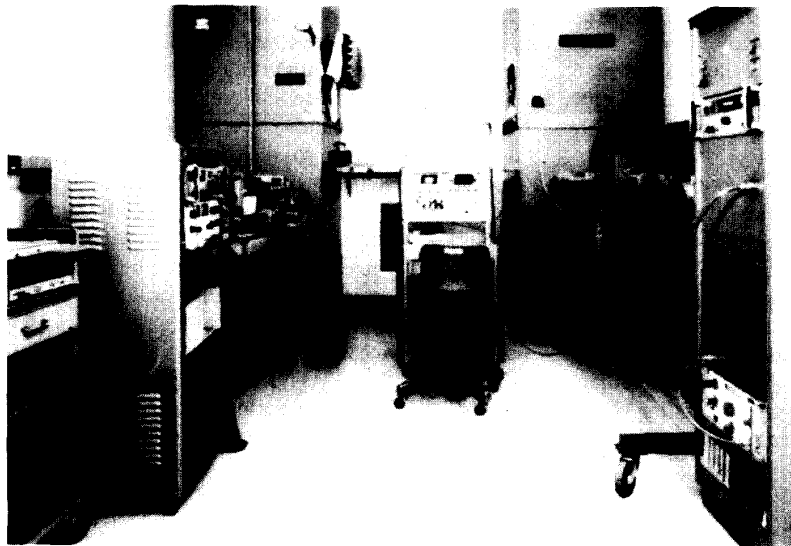


Fig. 3. Materials measurement facility.



Fig. 4. RAM-covered T-33.

allowed by the slotted line technique. In any case, after the impulse system was in operation, materials characterization became a trivial problem to RAM development.

In rather short time, the business of what controlled echo from aircraft became reasonably understood, and effort turned to what might be done about it. With absorbers coming along, and demonstrations with models showing progress in handling different types of echo sources, it had to happen that higher management got to the point of "suggesting" that something be flown to see if all this wonderful stuff worked in the "real world."

So it came to pass that a T-33 aircraft was chosen as a demonstration vehicle in the late 50s. With the great help of our friends in the aerodynamics and structures labs, this aircraft was completely covered with a broadband RAM and subsequently flown against a variety of specially-instrumented radars. This aircraft is shown in Fig. 4. The result of all the

measurements over a period of 18 months proved that 1) the echo was reduced to the same extent as predicted by model data previously, and 2) properly designed RAM could withstand the rigors of flight. We are not sure that flying this aircraft was the reason (the flight test people knew it as Bahret's white elephant!), but the pilot who flew it for most of the test period left to become an astronaut as soon as possible. He is shown in the aircraft, and his name was Gus Grissom—a very brave man.

Shortly after the T-33 activity, there were several other "demonstrations." One followed our simple diagnostic technique of putting a shaped cover over a suspected flare spot to observe the impact of the loss of its contribution to total vehicle echo. Through this method, we had shown that jet engine inlets were (are) major contributors to frontal RCS of aircraft. While we had not a thought that such covers could ever be used operationally, we did know that metal screens, with fine enough mesh, functioned like solid metal to a

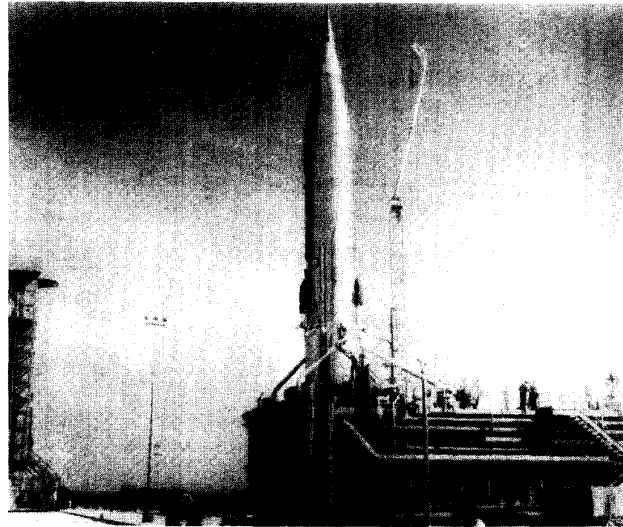


Fig. 5. Re-entry vehicle on launch pad.

radar. At least in principle, fresh air could get through the shaped cover.

Again, higher authorities "suggested" that a flight experiment be done, with aero and structures people worrying about the proper design of the screens. So it came to pass that I wound up with *two* B-47 aircraft—one to serve as the baseline, and the other, with metal screens over all engines, to demonstrate the amount, if any, of echo reduction. Crude as it was, this experiment proved again that properly taken model data did a fine job of predicting "real world" performance. Suffice to note that the F-117 has such screens today.

Another demonstration that followed good model test results, was an application to a re-entry vehicle. While our lab team was not directly responsible for this effort, we did participate as advisors to those who were, since materials and techniques we had developed were involved. Fig. 5 shows this special vehicle on the launch pad prior to its shot to a measurement site on an island in the Pacific. Once more, model testing was borne out by the "dynamic" test results.

It is regrettable that we cannot provide even qualitative results of all these interesting evaluations of the growing ability to reduce radar echo in operationally-useful ways. As we said at the outset, security restrictions prevent that, and with good reason—the same techniques are effective today. We remind the reader that we are talking about research that took place in the 1950s and 1960s.

To say that this job was fun, while being challenging, would be an understatement. Being virtually "the only game in town," during those early years, we were approached for help by people with all kinds of military interests who wanted to find out if this emerging technology might be useful to

them. Needless to say, there were many nibbles from contractor organizations who wanted our bodies as well as the information. But the one big factor that made a job change less than desirable was the opportunity to work on a variety of military systems, with the help of experts on those systems. The lab had no single interest!

We mentioned the ballistic missile previously, and Fig. 6 shows another totally different problem—a satellite. The picture is of one of the models of the Agena vehicle used for analysis of signature characteristics that were of concern at the time (early 60s). We cannot discuss this effort to satisfy the interested reader, but we can say that working in the space regime opened up so many possibilities for signature control that we were finally asked to stop demonstrating new ones until the first ones were digested. We will leave it that the opportunity to use inflatable devices, relatively free of many of the restraints imposed by "flying machines," made the work a very enjoyable and satisfying experience.

By now, the ability to minimize RCS had become more widely known, and we participated in the increasing number of initial operational applications. Again, security prevents even mentioning what these were, but while they were satisfying in the sense that anyone who works for many years enjoys seeing his or her efforts put to good use, there was the gnawing concern that the whole picture was not totally understood by those in positions to apply the technology to military systems.

We had demonstrated that almost any "conventional" system design could have its' signature reduced by proper use of different techniques. However, we no longer considered this to be a major achievement, since absolutely no concern had been

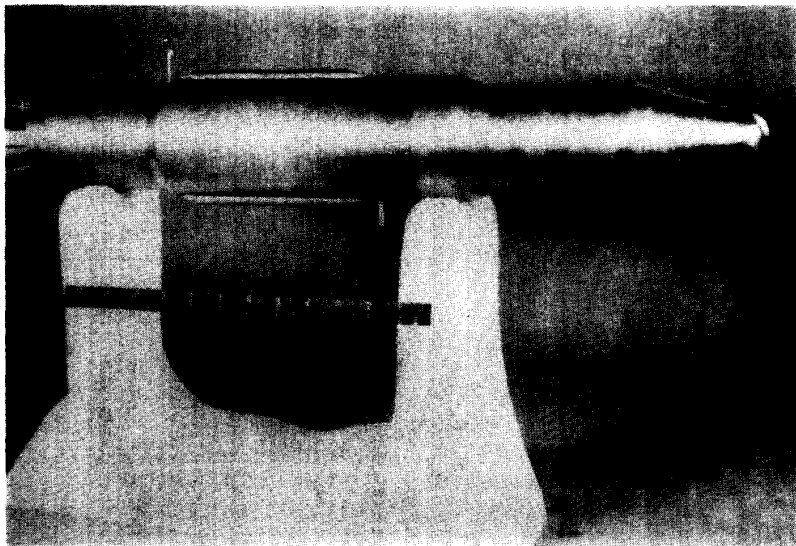


Fig. 6. Satellite model.

VEHICLE STATISTICS

GROSS WING AREA	200 FT ²
SPAN	134 IN.
CRUISE MACH	0.8
CRUISE RANGE	1500 NAUTICAL MILES
GROSS WEIGHT	4500 POUNDS
ALTITUDE AT INITIAL	
CRUISE WEIGHT	87,000 FEET
PAYLOAD CAPACITY	400 POUNDS, 10 FT ³

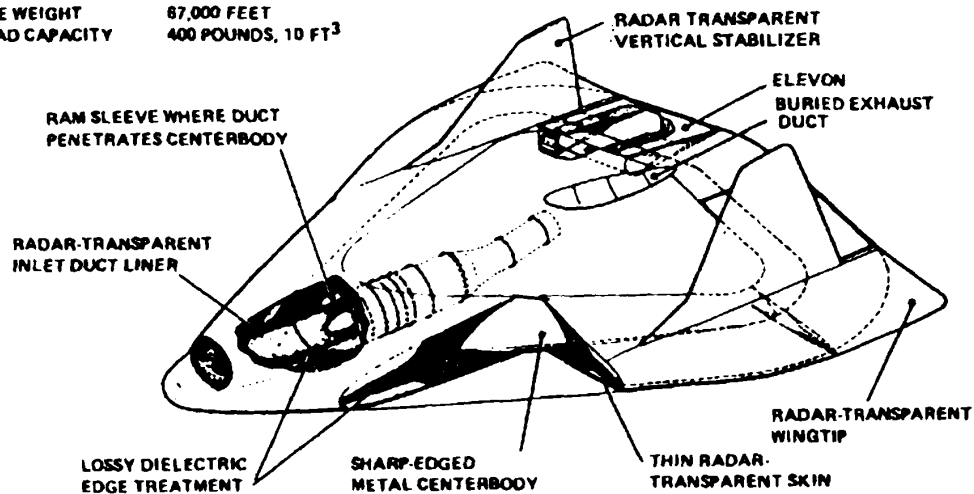


Fig. 7. Low RCS demonstration vehicle.

given to signature in the first place. What we had to do was show that minimum RCS could only be achieved by designing it in from scratch.

This led to a program in the mid 60s whose objective was to demonstrate, to the degree that an under-funded laboratory program could, what could be done if a flying vehicle was designed to have low RCS, as well as the normal aerodynamic, structural,

and environmental, capabilities. We assumed that the non-electromagnetic members of the community, who were so necessary to any further use of the technology in operational vehicles, would only be impressed if this "demonstration" vehicle had some useful mission capability, as well as low RCS.

This demo vehicle would combine all the lessons we had learned over the previous ten years or so

of research on reducing RCS—that shaping was the most important first step because it has major broadband effectiveness, that right angle junctions only created RCS problems, that transparency had to be used carefully lest something of even greater echo be exposed in the process, that apertures like engine inlets and exhausts had to be treated and hidden as much as possible, etc. The result was the unmanned aircraft shown in Fig. 7.

The range (1500 nautical miles), speed (Mach 0.8), altitude (above 67,000 feet), and payload capability (400 lbs./10 cubic feet) were chosen for a surveillance application, which was only a convenient example of a mission for a low RCS vehicle. The methods used to minimize RCS included a top-mounted engine, to “hide” it from radars below the vehicle, augmented by RAM treatment and selected transparency where useful. The entire body was shaped to provide least possible echo in the horizontal plane and below, at all azimuth angles. This critical part of the design was based on careful analysis of the most probable viewing angles available to “threats” during operational use.

After the shape was chosen, the RCS was further reduced by applying an absorptive edge treatment and again, selective transparency, around the entire body.

Fig. 7 goes as far as allowed in showing the design, but the reader can appreciate that most of the principles in use today are not entirely new. They have surely been refined through application to a variety of vehicles, mission envelopes, etc., but laws of physics are hard to change. Being part of the development of this powerful capability was an honor and a privilege never to be forgotten.

As stated several times throughout this text, security has necessarily imposed a great limitation on the content. The reader qualifying for more detail can certainly get it through classified source material available through the government.

The author would be remiss by not acknowledging all the many organizations—both government and contractors—who contributed to the development of the materials and techniques mentioned herein. The organizations and the key people are simply too numerous to mention here, and there would be the likelihood of over-looking someone even if that were tried. It is one thing to be in the position of leading a major activity like that discussed here, but clearly, the resultant capability is the accumulation from efforts by a large team, and that has to be acknowledged. This author does that with sincere gratitude.