Radar & the UFO

Martin L. Shough

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RADAR AND THE UFO

by Martin Lawrence Shough

■ **MARTIN SHOUGH**, Born 1953, Married, living in the village of Steyning, West Sussex, England. Enjoys painting, classical music (he plays a variety of instruments and has performed his own compositions on stage and on radio), and writing (he was a finalist in the 1986 Sussex Poet of the Year competition). He also enjoys the English countryside and English country pubs. A photo-lithographer by training, in 1985 he set up his own small publishing business.

■ **UFO involvement**: Since co-founding a Sussex UFO group affiliated to Contact UK which was active in the early 1970s, he has maintained an interest in anomalous phenomena. Specific interests are: the UFO problems and the philosophy of scientific method: statistical analysis: and radar/UFO events.

'UFOs are in the first place a problem not for physics but for psychology - the psychology of *our own attitudes*. We do not know what to believe; but more importantly we do not know *how* to believe or what we should accept as proof, as Ruppelt pointed out three decades ago. We certainly have a UFO problem, and what we need is not proof but therapy. The data *are* inconclusive, to be sure, but as Samuel Butler wrote, "Life is the art of drawing sufficient conclusions from insufficient premises."'

■ **Publications**: He has spent more than a year on a detailed study of one of the cases treated here, the Bentwaters/Lakenheath radar/visual case, to be presented in a forthcoming report at greater length .

Also in preparation is a uniform catalogue of reported radar/UFO events from 1947 to the present.

■ **Address**: 25 Mill Road / Steyning / West Sussex BN4 3LN / England. Phone 0903 81 3231.

The present article considers briefly the physical principles of radar; its capabilities and limitations; previous studies of the value of radar evidence in investigating anomalous aerial phenomena; selected radar and radar-visual events; some interpretations of the evidence; and conclusions and recommendations for further work.

THE NATURE OF RADAR

RADAR (RAdio Detection And Ranging) is an echo location system which displays the positions of targets within a certain volume of space around a transmitting/receiving antenna. Fundamental to all types of radar is the visual display of information on target range and azimuth [direction]. How this is accomplished in analogue primary surveillance radars will be described here since most of the events discussed involve such systems.

Radio energy in the microwave band is fed to an antenna which radiates a shaped beam, the antenna revolving to sweep a volume of space. Energy returned from reflective targets is gathered by the same antenna and fed to a cathode ray tube display which indicates by a bright spot or 'blip' the position of each target. Azimuth indication is determined by the orientation of the antenna when an echo is received, the electronic sweep of the radar scope being directly controlled by varying voltages from a potentiometer coupled to the antenna drive shaft. Range information is given by the round-trip time of the reflected energy, measurement of which is made possible by emitting the energy in pulses: after each pulse the transmitter is switched off and the receiver 'listens' for echoes collected by the antenna. Since the velocity of propagation of electromagnetic energy is known, the delay of the echo can be used to determine range.

In primary surveillance radars of the type under discussion, the whole process is managed in practice roughly as follows. A self-oscillating output device such as a magnetron, which produces its own pulse waveform, is fed by waveguides to a feed horn located at the focus of the antenna, whose geometry (typically parabolic) creates a shaped beam which is narrow in azimuth to give acceptable positional accuracy and broad in elevation to cover altitudes up to several tens of thousands of feet. Reflected pulses from targets caught within the beam are amplified and fed to the plan position indicator (PPI), which displays what is in effect a plan view or map of the area swept by the revolving beam. A received signal causes an electron beam to paint a luminous spot on the PPI at a position corresponding to the azimuth of the antenna and the echo delay time. Each returned pulse creates a spot of excitation, and because the radar beam takes a certain time to pass the target a number of pulses will be reflected with each sweep. The 'blip' therefore appears as a short arc (in the case of, say, an aircraft or similar 'point target') composed of the integrated spots from a number of consecutive pulses. A short period of persistence is usually designed into the screen coat-

ing so that the blip decays slowly (over perhaps a second or so), aiding the operator in interpreting the relationship of one blip to the next which may not be painted for several seconds.

Pulse lengths are on the order of one microsecond, and the pulse repetition frequency (PRF) is typically hundreds of pulses per second. The half-pulse length is the value which determines the range resolution of the set: thus, the range resolution of a 1 microsec. pulse which is 984 feet long will be in the region of 500 feet, meaning that the set will not discriminate between targets with a range separation of less than this figure. (In practice, this is a minimum because of the poorer resolution of the display; furthermore, one target may shadow another if they are in the same line of sight from the antenna.) Resolution in azimuth is a function of the width of the beam.

The analogue PPI display models the actual radar environment to scale and with a fidelity which is both bothersome to the routine professional user and of value to the researcher. Much of what appears on-scope before sophisticated signal processing has nuisance value in air traffic control but might be of interest to, say, meteorologists or ufologists: one man's signal may be another man's clutter.

CAPABILITIES AND LIMITATIONS OF RADAR

Every radar's radiation pattern is unique, being partially determined by the siting of the antenna in relation to local topography, and is furthermore inconstant in time due to changing propagation conditions.

Surveillance radar coverage is roughly a toroidal volume centered on the antenna whose depth and height above ground vary with range. As range increases power density falls, cross-sectional beam area increases, and the height of the bottom edge of the beam above ground also (beyond a certain threshold) begins to increase. This last property is due to the curvature of the earth's surface, which is greater than the curvature of the radar ray paths caused by normal atmospheric refractivity. The result is the creation of an artificial horizon below which (under typical conditions) no targets can be detected.

A model of the radar horizon as a simple line of sight modified by atmospheric refractivity is an idealisation never achieved in practice. The ideal surveillance beam shape towards which designers work has a sharp and level bottom edge, consistent range at all altitudes, and a level top edge with no power wasted at high altitudes where no aircraft will fly. In reality, the best approximation to this pattern attainable by antenna design is disturbed yet further by factors such as the nature of the terrain (its changing elevations and the varied scattering and reflecting properties of the surface), the height of the antenna above ground and its siting in relation to surrounding structures, and the differential of atmospheric transparency to radar waves, which varies with elevation. Furthermore, due to the inverse-square attenuation of electromagnetic radiation, the beam does not have a definite shape at all.

The result is a complex pattern which can be defined only by operational criteria. Nowhere within the radiation pattern is detection certain: the practical probability of reliability (and thus maximum range) might be, say, 90%, depending not only on the target but on the power of the radar, the sensitivity of the receiver and the noise-level of the amplifier, variations in elevation and reflectivity of the terrain and ground structures, and atmospheric conditions.

A further problem is 'lobing'. Although most of the energy goes into the main beam, its shaping has many ragged edges and some energy spills over into lobes radiating sideways, or even backwards 180°, and the receiver has the dubious benefit of antenna gain in these directions as well. The principal cause of lobing is reflected ground-incident energy, which interferes with the waves of the main beam to create finger-like lobes in the beam's vertical profile, generating a pattern of vertical coverage resembling a spread hand rotating from the wrist. The result is gaps and peaks which can cause targets to appear and disappear confusingly. Sidelobes are also generated which radiate at a significant azimuth angle from the main beam, though much attenuated, and there may be several pairs of these, becoming weaker as the angle from the main beam increases. The main problem is that since the target azimuth displayed on the PPI is always that of the antenna orientation, any targets detected in sidelobes will be displayed at spurious azimuths.

ANOMALOUS PROPAGATION

Further, the beam can be modified in startling ways if the normal refractivity of the atmosphere is altered by abnormal temperature and humidity. Under these conditions radar energy may reflect echoes from targets on the ground within or even far beyond the normal range. Normally diffuse, such grounds returns could, in special conditions, appear as isolated echoes resembling those from point targets. Even without anomalous propagation (AP) conditions, the radar scope can show all manner of weather returns (eg rain, hail) plus the permanent ground clutter of the radar's immediate environment, although there are methods to reduce or eliminate such problems.

MULTIPLE-TRIP ECHOES

Due to a phenomenon known as multiple-trip returns it is possible, under AP conditions, for the radar to display echoes at spuriously close ranges from targets which are in reality beyond the unambiguous range of the set. For a target moving radially with respect to the antenna its displayed speed and course will match its real speed and course; only the

range will be in error. For targets moving tangentially, displayed speed will be much slower than real speed (proportionally to real range) and courses may be very distorted.

GHOST REFLECTIONS

Multiple reflections of the transmitted pulse can occur between an aircraft and an efficient ground reflector (such as an empty lorry or metal building structure) or between two or more aircraft, generating spurious moving targets. Such ghosts appear beyond the aircraft range at a distance proportional to the added round-trip time to the reflector and on a radius passing through the aircraft; thus, as the aircraft flies past the reflector its ghost echo can attain high angular speeds and even appear to follow or intercept the aircraft.

RADIO FREQUENCY INTERFERENCE

Accidental RFI can be caused by other radars, voice communications, navigational aids and many other sources emitting in the crowded electromagnetic spectrum. Self-induced interference from a radar's own components can occur, and even out-of-band signals can, if strong enough, generate secondary intermodulation products which may be displayed. Typical interference effects are radial or spiral patterns appearing across the tube face, but sporadic interference pulses could produce brief, isolated false echoes, Since the spot will only appear on the PPI at the instant the interference occurs, a situation could conceivably arise whereby a cyclic source of interference emitting discrete pulses with a frequency slightly out of phase with the scan rate of the receiver would generate a series of 'echoes' slightly displaced on each scan, creating a false track.

INVERSION REFLECTIONS

A special case of anomalous propagation may arise when an elevated inversion layer partially reflects radar energy to the ground. The pulse may return by the same path and paint a spurious echo. Convincing moving targets may appear if, as is commonly the case, the inversion layer is rippled by waves moving across its surface under the influence of winds.

Less predictable effects may be caused by phenomena which are grouped under the heading clear air echoes or 'angels'. Many such echoes are now attributed to insects; however, relatively localised atmospheric structures are believed on occasion to produce direct returns on sensitive radars.

PREVIOUS STUDIES OF UFOS ON RADAR

Numerous authors have discussed radar and radar-visual events over the last four decades, but the status of this evidence has remained uncertain - indeed it has become less certain since the problems of interpreting radar images have become more widely understood in recent years. No single case has yet been accepted as unequivocal, although a handful of cases are sufficiently well documented and sufficiently intriguing to have been widely espoused as "probable" UFOs. Without exception the publicly available information on such events is inadequate to determine their cause, and in probably the majority of cases crucial data are either lost to us or were never recorded in the first place. To this extent radar evidence takes its place next to every other type of evidence available to the researcher, and one is reduced to estimating probabilities. This in itself is not an unusual situation at the frontiers of scientific research - fugitive and uncertain data are the very lifeblood of science - but it does demand a type of systematic analysis which has yet to be applied.

The number of radar events reported as UFOs is difficult to estimate. A NICAP compilation in 1964 listed about 60 [1], and a thorough search of the literature might be expected to yield about twice that number today. The proportion of events unreported is unknown but presumably large. Undoubtedly the watershed in radar-UFO studies was the Condon Report of 1969 [2] in which two previously unknown incidents appeared: Lakenheath, 1956, and South Central US RB-47, 1957. The Report was also the first study to attempt a collective analysis of radar events: 35 cases were examined for a variety of possible causes, the emphasis being on the question of whether anomalous propagation conditions could account for otherwise unexplained targets. Thayer's study [3] was based largely on USAF records from the Blue Book files and wherever possible utilised local radio refractivity index data to model propagation conditions at the time of the event. The result of this analysis was that 19 cases (or about 54% of the sample) were determined to be probable AP, 8 had explanations as man-made devices (about 23%), in one case there was no 'UFO' to explain, and in 7 cases (20%) Thayer's conclusion was 'unknown'. Of these seven cases Thayer regarded two as indicative of atmospheric propagation phenomena 'so rare that they may constitute unknown phenomena", whilst there was "a small but significant residue" of radar-visual cases which had "no plausible explanation" as man-made objects or propagation phenomena. Thayer recommended future investigation of both these categories of "unknowns", concluding with a list of desirable investigative procedures.

In the section of his summary 'Radar Sightings of UFOs' [4], Condon quotes Thayer's statement that "there was no case where the meteorological data tended to negate the anomalous propagation hypothesis". The scientific community ought to be shocked, not only because Condon failed to quote Thayer's relevant conclusions and recommendations, but because the remark he did quote is taken seriously out of context. Thayer was referring specifically to the sub-category of probable AP cases, not to the entire sample, and it is hard to resist describing

Condon's error as one of prevarication.

Subsequent to the Condon Report a number of significant publications appeared treating radar-visual events, and the two cases cited above yielded a rich harvest of new analyses. In December 1969 the American Association for the Advancement of Science Symposium on UFOs heard contributions dealing with radar events from three of its sixteen participants; Kenneth Hardy, an Air Force weather radar specialist; James McDonald, atmospheric physicist at the University of Arizona; and Donald Menzel, Harvard astrophysicist. Hardy discussed anomalous propagation, echoes from birds and insects, and backscattering from layered atmospheric structures, concluding that painstaking analysis has always been necessary to understand these and other once-puzzling radar phenomenon. Bewildering propagation anomalies may occur which will only be explained by well-designed experiments. McDonald's published paper discussed in detail four radar-visual events, two of which (the Lakenheath and RB-47 cases) had been evaluated as "unknowns" by Thayer. In his analysis of the 1952 Haneda AFB, Tokyo, and 1957 Kirtland AFB, New Mexico, cases McDonald disputed Thayer's conclusions of, respectively, anomalous propagation and unidentified private aircraft. McDonald concluded that there remained "scientifically very important unsolved problems with respect to UFOs", that the Lakenheath event in particular presented "evidence of some phenomena defying ready explanation in terms of present-day science and technology", and that acceptance of the Condon Report's negative recommendations would be "scientifically inadvisable." Menzel's paper discussed anomalous propagation effects studied during his US Navy radar research in World War II, pointing out that these phenomena were very puzzling to scientists and military operators until the theory of refractive trapping had been worked out. Similar phenomenon could account for targets reported latterly as UFOs. Menzel discussed the 1952 Washington DC National Airport incident, concluding that the Blue Book analysis attributing the targets to AP, endorsed by Thayer though contested by McDonald [5], was valid.

In discussion, Carl Sagan, planetary scientist at Cornell University, and Robert Baker, an astronautical engineer with UCLA and Computer Sciences Corporation, considered the possibility of using US space-surveillance defence radars to acquire new data on possible anomalous phenomena. MIT physicist Philip Morrison suggested that the "interesting" radar-visual events cited by McDonald could arise from "spoofing", possibly involving classified technology, as a test of defence readiness by friendly intelligence or foreign powers. Astronomer Thornton Page of Wesleyan University observed that whilst the reality and solidity of radar targets is in general very difficult to establish without collateral evidence, the combination of several simultanenous observations makes the presence of a solid object very probable. In a short written contribution, David Atlas, University of Chicago radar propagation specialist, commented that although some radar observations require 'almost incredible atmospheric structures' to be explained as AP effects, nevertheless it is reasonable to expect that such structures will be understood in time. [6]

In July 1971, the journal of the American Institute of Astronautics and Aeronautics published an account by McDonald of the 1957 RB-47 incident [7] and in September 1971 an analysis by Thayer of the Lakenheath event. Both papers recommended further investigation and were widely regarded as signalling a new level of professional respectability for UFO studies.

1972 saw the publication of a book by J Allen Hynek, astronomer at Northwestern University and former scientific consultant to Blue Book, in which ten radar-visual events were outlined with the conclusion that 'good radar-visual cases, properly investigated, are rare. Those that do exist, however, cannot be easily dismissed.'[8] A different conclusion was reached by avionics journalist Philip Klass in 1974.[9] Klass presented lengthy analyses of the Lakenheath and RB-47 events in which he was highly critical of the conclusions of Thayer and McDonald and developed ingenious scenarios to explain both cases. In general, Klass felt that anomalous radar phenomena could all be explained by conventional objects, malfunctions and meteorological principles, compounded by the 'susceptibility of radar operators to being misled by spurious targets.' Klass's work is undoubtedly among the most influential in the radar-UFO literature.

There has been little movement towards consensus on the status of radar events in recent years, though a mood of cautious scepticism has spread through ufology since the mid-seventies which is reflected in a less sanguine attitude to the trustworthiness of radar evidence. The complexity of the radar environment aside, cases enjoying the benefit of preserved scope photographs, tapes or even contemporary written logs are very rare, and so the soft-data problem of interpreting human testimony to a large extent remains. In 1979 Randles and Warrington wrote:

"In our examination of cases involving radar observations we have found enough indication that almost all can be explained in terms of possible imperfections or misinterpretations of the displays, and see little substance in the alleged evidence provided by such cases." [10]

They make the interesting observation that the majority of cases on record belong to the 1950s, and argue that there are "no known recent radar observations", suggesting that this can be explained by the "troublesome adolescence" of radar development. Although it is a considerable overstatement to assert

that radar events are an extinct ufological subspecies, it is true that the number of known incidents has fallen in recent years. This trend may have a different interpretation, however, as we will see later.

In summary, it has to be said that there has been very little in the way of systematic analysis of the radar-UFO data available. The data are only accessible through a search of scattered sources, and until a central file can be assembled few meaningful conclusions are possible about the class-properties (if any) of the total population of "unknowns". We will see that some tentative conclusions may be drawn from the study of small samples, but these are inevitably compromised by uncertainties about the reliability of much of the information. Forty years on, the radar evidence for unknown aerial phenomena still rests on the precarious credibility of a handful of individual cases.

SELECTED EXAMPLES OF RADAR-UFO EVENTS

■ SELFRIDGE AFB, MICHIGAN, 9 MARCH 1950

Two factors make this an intriguing case: from a scientific point of view, the detection of what was apparently the same unidentified target on two radars of different design; and from an historical point of view, that it led to high-level official recommendations through channels bypassing the low-priority Project Grudge system for fresh action on radar UFOs. A SECRET letter from the Air Adjutant General, Headquarters Continental Air Command, to the Director of Intelligence, Washington DC, concluded:

"The frequency of reports of this nature has recently increased; instructions have therefore been directed to all radar installations within this command to report scope sightings of unusual objects... It is recommended that reports of unidentified object sightings be reconsidered for submission from all Zone of Interior Air Force agencies." [11]

The event which prompted this letter occurred during radar monitoring of a night flying exercise by F-80s of the 56th Fighter Interceptor Group near Selfridge. A target was observed by an Air Force radar controller and three other operators on the PPI of the CPS-5 surveillance radar and simultaneously on the HRI (Height Range Indicator) scope of the CPS-4 height finder. The height finder emits a horizontal fan beam from a nodding antenna and operates at a very different frequency (S-band) from that of the CPS-5 (L-band). The "clarity, narrowness and definition of the presentation was definitely that of an aircraft" and comparable to the return from an F-80, according to the controller. The target moved with rapid alterations in height and speed, generally in the area of the fighters and "sometimes approximating their courses", but about 20,000 feet above their highest assigned altitude (checked by radio) of 24,000 feet. Over a period of 6 minutes the controller and another operator noted range, height, azimuth and time data in grease pencil on the scope heads. The target was observed for over an hour, during which time "several extreme instances of gaining and losing altitude" were observed, the target on the HRI scope rising and falling "up to 20,000 feet very rapidly" with "erratic" changes of speed observed on both scopes. On at least two occasions the target hovered motionless for a mean period of two minutes. Maximum stimated speed was 1500 mph, although the controller noted "the possibility of inaccuracy" in the timing at this point. Later, when the target was "giving indications on both scopes without fade", logged speeds were between about 330 and 480 mph, with climb rates up to 6000 ft/min. The highest logged climb rate coincided with the highest logged ground speed. The motion of the target during the six minutes before contact became intermittent on the CPS-5, and thereafter on the CPS-4, fading finally at 120 miles, are shown in **Figure 1.**

The controller's report on this incident, which is one of the most admirably careful documents of its type on record, states that positional checks performed with the F-80 pilots established that the CPS-5 was "very accurate on this particular night" and that no "known or prevalent weakness" of the CPS-4 could be found to explain the HRI indications. "All possible errors" were explored "exhaustively" with base technical personnel without result.

The Project Grudge evaluation of this case was "unidentified", but with the rider: "probable balloon". No specific balloon launch could be indicted, nor did Grudge offer any defence of this evaluation. Indeed it is hard to see any grounds for suspecting a balloon given the astonishing windspeed implied and the fact that the target evidently moved in many directions. Heading for the 1500 mph run was roughly NE, for example, whereas the target departed on a heading roughly SE. Furthermore, the faster run occurred earlier when a balloon would be lower, which is the opposite of the behaviour natural to a balloon climbing through winds which increase in velocity with altitude.

Birds, insects and ordinary weather returns cannot account for the target. Nor is it likely that instrument faults or remote RFI could affect two electronically independent radars with different receiver bandwidths - mutual interference being similarly improbable. No effect attributable to sidelobe returns could account for such a target. Anomalous propagation is a poor hypothesis in this case because the refractive effects due to atmospheric temperature/moisture gradients are very sensitive to frequency: as the analysis by USAF radar specialists noted, "the great difference in frequencies...and the evident correlation of observations almost rule out the possibility" of AP. No purpose is served by supposing multiple-trip effects: firstly the p.r.f. of each set must be the same; secondly, ground returns due to super-refractivity are

azimuth whereas in this case a fairly consistent pattern of behaviour was observed at azimuths differing by 180° (it strains credibility to imagine that multiple-trip returns from different targets at various azimuths could give the appearance of a series of connected movements by one target). Clear air echoes by direct returns from microscale atmospheric discontinuities are ruled out by the speeds observed. Forward scattering from moving waves on an inversion surface is ruled out also by speed, by the frequency sensitivity of this effect (which makes echoes on both 'scopes improbable), by the divergent headings of the target (thus independent of winds), by the rather high elevation of 6° shown by the HRI (too high for grazing incidence), by the repeated stationary episodes, and by the attenuation of the signal as it approached the extremes of its displayed range, becoming intermittent and finally fading (which is the opposite of the behaviour of echoes due to forward scattering, which decrease in intensity with *proximity* to the antenna as a result of the increasing incidence angle). No aircraft flying in 1950 could remotely approach the performance displayed by this target: even helicopters could not hover at such altitudes out of ground effect, and speeds of 480 mph would only be attained by a fighter using a considerable percentage of full power; even allowing wind speeds at 30,000 feet of perhaps 100 knots a helicopter would be too slow and could not achieve climb rates up to 6000 ft/min with a simultaneous ground speed of 480 mph.

The only half-plausible hypothesis in this case is that of a 'ghost' - a secondary echo from an aircraft due to either a ground reflector or another aircraft. Details hinting at this are the consistent high altitude of the target (roughly twice the altitude of the F-80s being monitored), the controller's statement that the "presentation was definitely that of an aircraft" but smaller than the F-80 returns, and the fact that the target "seemed to stay in the area in which our fighters were flying, sometimes approximating their courses." A ghost due to one of the F-80s would always appear on the azimuth of that aircraft but at a greater range and altitude. The F-80s were flying at 24,000 feet and *below*, so that the target altitude of (initially) about 45,000 feet *could* fit a ground reflection; but the relative ranges and azimuths are unknown. Arguments against a ghost reflection, however, are rather strong. Firstly, the repeated stationary episodes rule out a ground reflection. For a reflection between two aircraft to achieve this would require a reflection geometry that is possible, but highly improbable even once let alone twice, and certainly not for periods of two minutes. The consistent presentation of a single good return on both scopes for periods of several minutes, plus a consistent track heading during departure over a distance of about 50 miles or more, are not features suggestive of reflections between aircraft.

Of importance to show the interpretation of this event is the failure of the CPS-5 to at first show the target indicated by the CPS-4 at high altitudes. This is not easily understood in terms of a ghost reflection from an F-80, since the aircraft responsible (*ex hypothesi*) was simultaneously being painted by the CPS-5 and the reflection geometry would be the same for both radars, as it obviously must be (again, *ex hypothesi*) to account for the subsequent simultaneous paints. On the other hand, the relative performance of the two radars does make sense in terms of their practical capabilities with real targets at high altitude. As the report of technical personnel, Headquarters, Continental Air Command, pointed out:

"Further validity is lent to the contention of the reports by statements that first indications, which were at high altitudes, were observed on the CPS-4 height-finder before being observed on the CPS-5 surveillance radar set. This follows logic and field experience, inasmuch as the high-altitude coverage of the CPS-5 is known to be poor... It is to be noted that previous field experience with a CPS-5 surveillance radar set has indicated that targets picked up at ranges and altitudes indicated in subject report would probably have a reflection aspect ratio on the order of magnitude of a B-29 or greater." [11]

■ KANEDA AFB, TOKYO, AUGUST 5-6 1952

This case was carried as "unidentified" in Project Blue Book files, and has been subsequently analysed by Thayer [3] and McDonald [12]. Thayer suggested that this radar-visual event could be explained by anomalous propagation and a diffracted image of the star Capella, conclusions contested by McDonald.

At about 2330 local time on the night of August 5, two Haneda control tower operators observed a blue-white light of unusual brilliance in the NE and began studying it with binoculars. About ten minutes later, Haneda tower received a telephone call from Tachikawa AFB, 21 miles WNW of Haneda, independently calling attention to a "brilliant light over Tokyo Bay", a direction which, as McDonald pointed out, implies a bearing significantly south of east. These two lines of sight [**see Fig.2**] intersect in fact over the northern part of Tokyo Bay, where radar contact was subsequently made by ground radar and airborne intercept radar.

Haneda called the Ground Controlled Intercept (GCI) radar unit at Shiroi (N of Tokyo Bay) shortly after 2330 asking if radar had a target on a bearing NE from Haneda. The Shiroi CPS-1 surveillance scope showed three or four stationary targets "at a position 050° bearing from Haneda, as reported by the tower", over Tokyo Bay. The CPS-4 height finder could not pick up the targets, but it was noted that ground clutter was excessive at the low altitudes visually estimated by Haneda tower, and it is consistent that the targets could only be detected on the low beam of the CPS-1. For 15 minutes no change

was reported from Shiroi and visual observation of the light continued from Haneda. According to the tower operators, the light rose slowly by a few degrees during the hour it was in sight.

At 2345 a target was detected on the Shiroi high beam and an F-94B was scrambled from Johnson AFB to the west. The F-94B got off at about 0003-4 after a delay due to fuel system trouble. At 0001 Shiroi had a target in a right orbit of 4 miles radius over Tokyo Bay, speed varying from about 100 - 150 knots and "stopping and hovering occasionally". When the target's orbit took it inland it was partially lost in the CPS-1 ground clutter pattern near Tokyo. At about 0012 the target emerged from the clutter and commenced a second orbit, fissioning now into three targets, one somewhat brighter than the other two. The three targets maintained about one-quarter mile separation through the second similar circle over the bay. As the targets reached the southernmost extent of their orbit and began to turn north of west back towards the coast, the interceptor, coming down over the NW of the Bay, was given a vector of 320° onto the largest target and instructed to search for the object at 1100 o'clock, range 4 miles. The time of this vector was 0015. At 0016 the 3 cm APG-33 air intercept radar on board the F-94B picked up a target at 10° port, range 6000 yards, coinciding very closely with position supplied by Shiroi. The interceptor followed the target in a starboard turn as it moved rapidly across the scope, both aircraft and unknown being painted by CGI radar. The unknown target had increased speed to between 250 and 300 knots as the interceptor approached, and now pulled away from the F-94B which was unable to close to within its radar lock-on range of 2500 yards. Pursuit continued for one and a half minutes until the APG-33 lost its target and both aircraft and unknown disappeared into the ground clutter pattern of the CPS-1. At 0017 30 Shiroi GCI recalled the interceptor to search the area of the Bay, without result, and at 0033 Shiroi released it from its mission, handing off to base control at Johnson.

In this case the extent of the correlation between radar and visual sightings has been subject to dispute. Both Thayer and McDonald argue that the object seen from Haneda was probably not related to the orbiting target intercepted by the F-94. McDonald's argument is that no lateral movement of the light was reported great enough to correspond to the arc of 30° subtended by the diameter of the radar orbit (8 miles) as seen from Haneda. Thayer remarks that in addition the light was still visible from Haneda at least 5 minutes after radar contact had been lost and the "UFO had left the area at a speed well in excess of 300 mph." That the object (if there was an object) had left the area is of course an assumption based on loss of the target from the AI radar and failure of Shiroi GCI to plot its emergence from the Tokyo ground clutter. It is possible that the "object", though lost to the radar, remained in the area to be seen visually for a few minutes.

The question of the movements of the light seen from Haneda is more interesting, and McDonald called this "the single most important ambiguity in the case file." He conceded that "the weight of evidence" does indicate that the object was seen to move, but concluded (a little inconsistently) that this movement had no relation to the orbit of the radar target. Yet the tower operators' statements describe

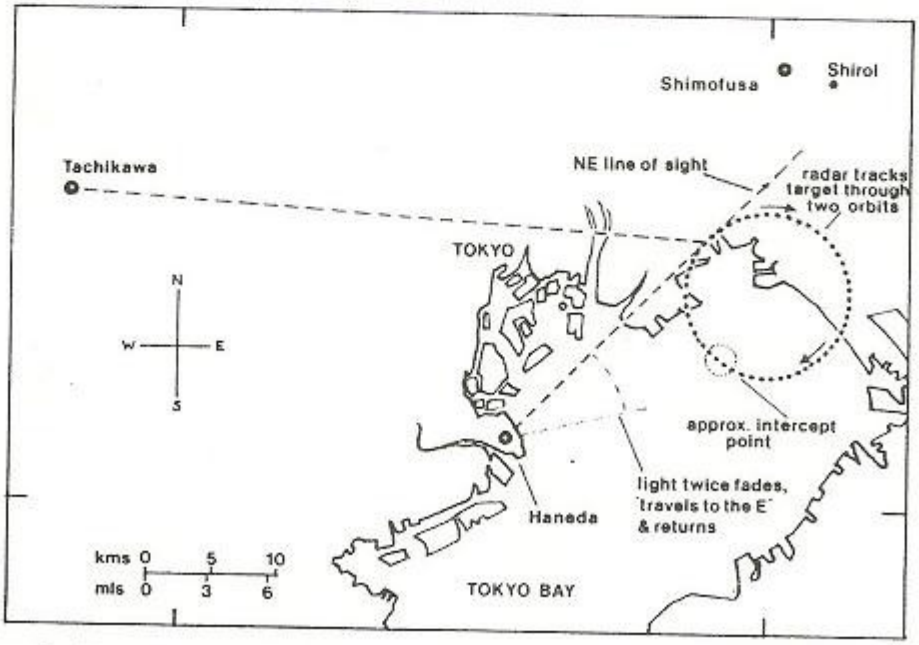


Figure 2 - Map of radar and visual sightings made in Tokyo Bay area, 5-6 August 1952.

the light initially stationary in the NE-NNE, then travelling to the E with an apparent gain in range so that it "became difficult to follow closely, except as a small light", returning to a stationary (or nearly stationary) position in the NE at its original brightness, then repeating the movement to the east and back before disappearing "when the jets (sic) were around... it seemed to know they were there." One controller stated: "I watched it disappear twice through the glasses. It seemed to travel to the East and gaining altitude at a very fast speed, much faster than any jet." Granted that these statements are not as clear as they might be, nevertheless phrases such as "travel to the East" from a position NE-NNE and "difficult to follow closely" at least arguably imply non-radial motion, and the fact that this motion was observed twice is rather easily related to the two wide orbits made by the radar target. Motion from NE "to the East" is not inconsistent with the 30° subtense of those orbits at Haneda, even if the times and exact bearings cannot be established.

Thayer attributed the light to a dramatically diffracted mirage image of the star Capella, which was at 8° elevation, 37° azimuth from Haneda at 2400. The light was described as "intense", "brilliant" and "blinding" enough to fatigue the eyes of the obsrervers and was of a blue-white colour. McDonald argues that since estimates of size and brightness were scaled directly against known light sources and a pilot balloon by tower personnel, these estimates should be taken seriously. Roughly consistent magnitude estimates emerge from comparisons made with Jupiter (appearing low in the east and looking relatively faint by contrast with the object, though with a magnitude itself of about -2.0) and with a 1.5 candle light carried by a meteorological balloon released from Haneda at 2400 with a known range from the tower of 2000 yards. McDonald estimated a magnitude substantially brighter than -3.0 for the object. The angular size of the light, which was large enough to be described as circular in shape, was scaled by comparison with the known diameter of the pilot balloon and comes out at about 3.0 minutes of arc, or about one-tenth the apparent size of the full moon. Further structure was visible around the central disc: a broad, dark annulus (described as a 'round dark shape' or 'darker object') about 12 arc minutes in diameter with three or four smaller lights around the curve of its lower edge. Only the lower edge of the dark shape was distinguishable from the sky background, and there was "a glare around the whole thing". This detail was observed through 7x50 binoculars.

An attempt by Thayer to account for this display by an admittedly conjectural propagation mechanism (which 'must be quite rare') involving a sharp temperature inversion overlaying collected patches of mist and through which the image of Capella would generate an annular diffraction pattern, was minutely criticised by McDonald on a quantitative basis. The possibility of illusion due to optical contrast effects, however, cannot be ruled out as an explanation for the reported structure.

The independent line of sight to the object from Tachikowa was, as McDonald emphasised, more than 45° away from Capella. However, it was only a few degrees from the position of Jupiter which was bright in the east, so the possibility should be considered that this sighting was of Jupiter. Set against this, it is impossible to estimate the likelihood of independent simultaneous misinterpretations of two different astronomical bodies, but the probability is presumably low, particularly when combined with subsequent multiple-radar contact with a target appearing to correlate with motions observed visually and detected in the area triangulated by these two independent lines of sight.

There remain many unanswered questions in this case. Why was the object not observed visually from Shiroi or from the interceptor? Why were three radar targets initially acquired when only one object was seen visually (unless, of course, one assumes that the three or four smaller lights seen close to the central light somehow correspond to these targets)? Why was only one object seen visually even after radar reported the target fissioning in three? Despite these and other anomalies, the radar events alone are very difficult to account for and AP involving orbital tracks and concurrent air/ground detection at very different frequencies and incidences seems out of the question. In summary, attempts to explain this event to date appear too contrived and require too many assumptions and coincidences to be probable.

■ LAKENHEATH, NEATISHEAD AND BENTWATERS, ENGLAND, AUGUST 13-14 1956

Since the publication of the Condon Report, this has been the most famous radar-visual case in UFO history. Analyses by Thayer [3,13], McDonald [12,14] and Klass [9] are the major published sources, with many other more or less accurate presentations scattered through the literature. Thayer and McDonald concluded that most or all of the radar indications observed had no adequate explanation, whilst Klass argued that typical AP effects compounded with equipment failure and observer error could explain all details of the case.

This sequence of events occurred over a six-hour period between 2130 GMT on August 13 and 0330 on August 14 1956, and involved multiple concurrent radar and visual observations of what appeared to be high-speed, self-luminous objects displaying unconventional manoeuvrability. The opinion of personnel involved and the conclusion of subsequent base-level investigation at Lakenheath was that the radarscope images represented airborne radar-reflective targets of unknown nature. At least five separate incidents were reported, involving at various times six ground radar sets and one airborne interception radar. Four incidents involved

Ground Controlled Approach (GCA) radar at Bentwaters USAF base; a fifth involved coastal air defence and Ground Controlled Interception (GCI) radars at Neatishead, Norfolk (RAF), Air Traffic Control (ATC) radar and GCA radar at RAF/USAF Lakenheath, in addition to AI radar aboard an RAF interceptor. Some twenty radar personnel were directly involved, with up to nine air-visual and ground-visual observers reporting related sightings. During the principal phase of the fifth event, correlating targets were simultaneously observed on at least five (possibly six) of the above radar scopes, concurrent with possible ground-visual and air-visual observations, and were interpreted as returns from a high-speed object exhibiting apparent control.

The following qualitative precis establishes the sequence of events and their general context as indicated by the contemporary Blue Book intelligence reports, the statements of the Lakenheath ATC Watch Supervisor, and the testimony of the RAF Chief Fighter Controller at Neatishead. There are inevitable gaps and contradictions after more than 30 years which will be addressed (briefly in the space available) in due course.

Late in the evening of August 13 a single high-speed (estimated 4000 mph) uncorrelated target was detected by Bentwaters GCA radar. At about the same time some 15 slow-moving targets crossed the scope in a different direction, appeared to merge on the display, then moved off-scope. Five minutes later another single high-speed target was observed to cross the scope on a heading different from either of the previous tracks. Less than an hour later a further single high-speed target crossed the scope on a heading the same as the previous target, and simultaneously visual observations were made by control tower personnel and the crew of a transport aircraft in a landing pattern over the field of a "bright light" which passed over the field and "under" the aircraft. At this time Bentwaters GCA alerted Lakenheath requesting confirmation of any uncorrelated targets.

At some time subsequent to this alert, ground observers at Lakenheath independently reported a luminous object approach the field at low altitude, stop, then move away on a different heading. Later two similar objects were observed which approached one another then moved away "in formation together." At this time Lakenheath GCA radar operators were observing targets in the vicinity of the base which exhibited "substantially the same" behaviour. One stationary target was observed 20-25 miles SW of the field and thus in a position to be detected by ATC radar (which had a 7-mile minimum range). ATC Center called GCA asking if they had a target at the above location: both scopes showed the target, which was puzzling to ATC personnel because the Moving Target Indicator (MTI) on their radar should have eliminated stationary targets. After a few minutes the target began to move at a speed of 400-600 mph and again stopped suddenly about 20 miles NNW of the field.

At this point the ATC Watch Supervisor called his superiors and reported the situation. As the target continued its high-speed straight-line movements around the area, a conference line was set up from the ATC radar room. The AF Communications Squadron Commander, the Base Commanding Officer and others, including an RAF liaison officer, were all patched in and at length a decision was taken to scramble two RAF interceptors. By this time Neatishead GCI had been alerted and could see the target on their scopes also as the first of two Venom NF2a nightfighters from RAF Waterbeach approached Lakenheath under their control.

Watched by radars at Lakenheath and Neatishead, about forty miles NE, the Venom was vectored onto the target, reporting radar contact and visual contact. As the interceptor closed range, AI radar lost the target and simultaneously ground radars showed the target circle rapidly behind the interceptor to begin a tail-chase. For some minutes the pilot attempted to shake the target from his tail unsuccessfully. About five minutes into this engagement the target was lost on Neatishead radars with a rapidity which was interpreted as a sudden descent out of the radiation pattern, and shortly the pilot was released from GCI control. Lakenheath continued to display the target as it followed him a short distance in the direction of Waterbeach. About 10 miles S of Lakenheath the target stopped and remained stationary, executed one or two short moves, then left Lakenheath radar coverage at a constant 600 mph to the north.

The complexity of this case is such that to do it justice would require a good-size book. [A detailed report is currently in preparation. MLS.] Here, a few of the apparent problems raised by ambiguities and contradictions in the source material will be mentioned and some interpretations of the evidence briefly reviewed.

Firstly, let us look at the four radar events at Bentwaters between 2130 and 2255. Of these only one involved simultaneous visual observations; nevertheless all four events are difficult to account for by conventional aerial objects or propagation/electronic anomalies. Three events involved single high-speed targets resembling aircraft returns which crossed the scope from one sector to the opposite; the remaining event involved a slow-moving cluster of targets which also crossed the scope center (approximately) between opposite sectors. The essentially radial motion of all these targets is interesting. Such motion on a radial-timebase PPI is at first sight suggestive of spurious signals generated somewhere in the amplifier or receiver circuitry. However, the motion of a target due to a spurious input between opposite sectors in this way would require an impossibly fortuitous relationship between two different and immediately

consecutive input pulse patterns synchronised to the half-rotation period of the display. The notion of electronic artefacts has been advanced by Klass [9], but nothing short of a very sophisticated electronic-countermeasures simulation exercise could create a false target in this way, and the existence of such a capability with 1956 analogue technology is hardly credible.

No known propagation mechanism can account for targets with displayed speeds of thousands-of-mph. Some attention has been given, however, to the possibility that the cluster of slow targets at about 2130 might have been due to partial reflection from moving waves on an elevated inversion. This hypothesis was advanced, with reservations, by Thayer; rejected without reservations by McDonald; and adopted without reservations by Klass. Central to this hypothesis is the relationship between the reported target motion and the speed and heading of the winds over the Bentwaters area. Since the radar displays slant range to the target according to the total out-and-back path length of the reflected signal, and since the geometry of reflection from the layer to the ground and back doubles the path length, it is obvious that displayed range will always be twice the actual slant range to the moving wave. Thus, as the wave propagates across the inversion surface at wind speed, the reflected echo moves across the PPI in the same direction at twice wind speed. Klass points out that the cluster of echoes "faded considerably" during their recession NE, and the "winds aloft were to the *northeast* - the direction that the cluster of UFO-blips was moving." Furthermore, the reported speed of the echoes (between 80 and 125 mph) is "roughly twice the velocity of the winds aloft that night." [9]

On the face of it, this relationship is convincing. But there are several considerations which argue against inversion reflections, of which we shall mention three.

Firstly, the relationship with wind direction is not as unambiguous as Klass and (to a lesser extent) Thayer suggested. Surface winds were indeed within a few degrees of the reported heading, blowing from 230°. But these are not the winds whose speed Klass quotes. Surface winds were only 5-10 knots, so unrelated to target speeds of 80-125 mph. Winds in the correct range of speed occurred above 6000 feet, but these winds were steady from 260° and so *about 35° from the reported target heading*. Thus such an assumption ought not to be imported without discussion.

Klass's study emphasises the merging of this cluster of returns into a single stationary target, but makes no attempt to interpret this behaviour. Thayer, however, remarked that "the reported stationary episodes...would, taken at face value, rule out the moving-layer reflection hypothesis..." [13] These two stationary periods (in the face, *ex hypothesi*, of up to 60 mph winds) for a total duration of many minutes make no sense in terms of reflections from an elevated layered structure, and there is no internal reason to dismiss these rather specific details.

Probably the strongest argument against the inversion-reflection hypothesis concerns the reported fading of the returns beyond a range of about 14 miles, which feature Klass appears to regard as symptomatic of an unreal target. But the intensity of a signal returned from a distant ground target by a partially reflecting layer exhibits precisely the opposite of the reported behaviour. The targets were first observed at a range of 8 miles, overflew the radar appearing "as normal targets on the GCA scope", then "faded considerably" at about 14 miles in total contrast to the behaviour characteristic of inversion reflections.

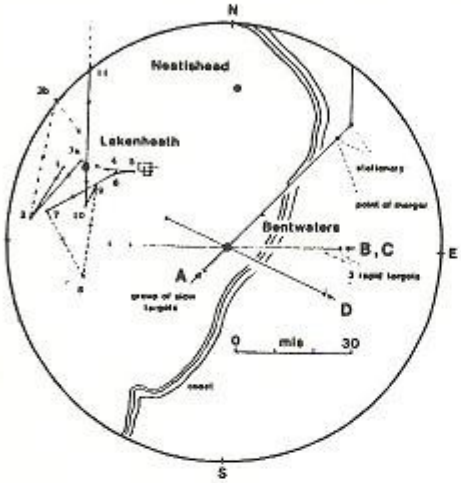
The final event at Bentwaters, the 2255 radar-visual, raises the question of the Perseid meteor shower which has been regarded by some commentators (in particular Klass) as responsible for this and most other visual reports made that night. In fact, the original Lakenheath intelligence report contained the statement: "Observers report unusual amount of shooting stars in sky. Further state the objects seen were deinitely not shooting stars..." Hynek's 1956 evaluation as consultant to Blue Book noted this statement and rejected the Perseid hypothesis as "highly unlikely". Meteor wake returns would seem like a simplifying explanation, but the CPN-4 surveillance scope could not have picked up wake returns for reasons including the power and frequency of the set and the geometry of the track in relation to the antenna, in addition to which the reported speed is an order of magnitude too low. Furthermore, the position of the Perseid radiant is *50° away* from the reported heading.

Moving on to the subsequent incidents at Lakenheath, the centrepiece of the entire case is the interception, when so many ground and airborne radars painted the same target simultaneously. No serious attempt has been made to explain this extraordinary phenomenon, nor does it seem likely that any explanation will be forthcoming. The Neatishead GCI station (or "Happidrome", as such installations were quixotically known) consisted of no less than five electronically independent radar units from which height, range and azimuth data were fed to a range of consoles, the combination of inputs being selected by the operator for display according to the changing situation during intercept. The entire control and display system was duplicated in back-up and monitored by a second interception team. This system alone brought into play radars with different frequencies, different pulse lengths and possibly different PRFs. [19,22]

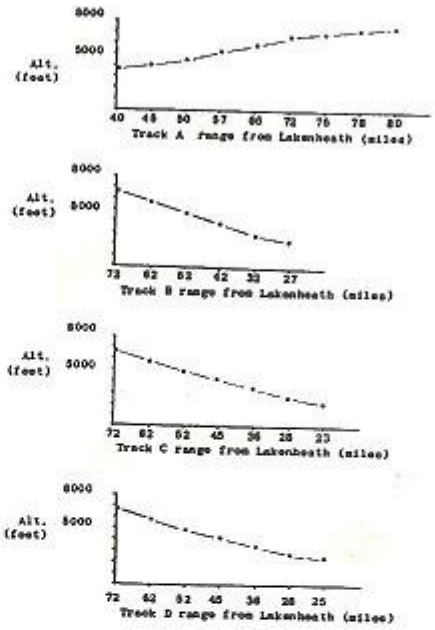
At Lakenheath, the L-band radar introduced a third frequency and a different PRF. It is implied that the S-band GCA CPN-4 continued to track the target during the interception, though attention is focused on the role of ATC at this time. The Venom's AI radar,

a modified American SCR-720 with the very British designation of Mk.10, operated at a wavelength of 9 cm with a PRF variable from 375-1500 Hz depending on range-scale.

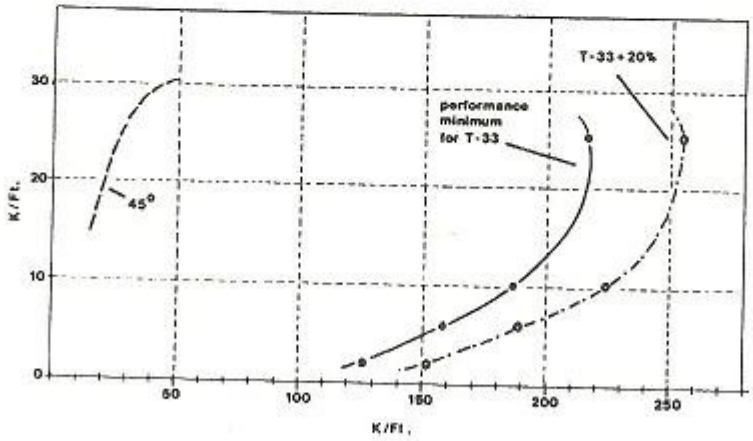
Lakenheath and Neatishead are separated by some forty miles, and the area of the interception in the southerly sectors from Lakenheath and southwest from Neatishead covered perhaps 200 square miles or so. Under these circumstances, the chance of a freak reflection echo (seriously proposed by Menzel [15]) creating a 'ghost' of the Venom is essentially nil, and no known propagation anomaly corresponds either to the behaviour observed or to the various separations, azimuth/elevation angles



3.a. Unexplained radar targets at Lakenheath & Bentwaters.



3.b. Lakenheath CPS-5 radar horizons at ranges of targets tracked by Bentwaters GCA radar.



3.c. CPN-4 surveillance radar at Bentwaters and Lakenheath GCA units. Showing performance minimum and minimum-plus-20% for a T-33 in low altitude cover. Cosecant^2 pattern up to 45° also indicated.

Figure 3 - Radar observations at Bentwaters, Lakenheath and Neatishead, 13-14 August 1956. 3A) Map of radar tracks within circle representing Bentwaters' CPN-4 maximum range. 3B) Lakenheath CPS-5 radar horizons at ranges of targets tracked by Bentwaters. 3C) Range/altitude performance of CPN-4 for target cross-section equivalent to a Lockheed T-33 jet trainer.

and frequencies of these several fixed and mobile radar systems. Multiple-trip effects and electronic faults are also ruled out. It is very hard to conceive of any sort of atmospheric structure which could achieve the speeds and movements independently reported, or mimic in such fashion the appearance of rational behaviour. The target was not weak or intermittent but consistent and of a strength comparable to that of the Venom, according to the RAF Chief Fighter Controller, who adds that it appeared in every respect to be an aircraft target except for its extraordinary speed and manoeuvrability. [17,19]

Much controversy has surrounded certain attempts (especially by Klass) to de-mystify the events by means of highly ingenious interpretations of the testimony. Firstly, doubts have been expressed about the apparent absence of concurrent radar detection by Bentwaters and Lakenheath. The Bentwaters targets should, objected Klass [9], have been well within range of Lakenheath's CPS-5, and the Lakenheath events fell largely within Bentwaters' CPN-4 range. Thayer also found this "slightly disturbing". [13] Yet it does not by any means follow that targets within the ranges of two radars will be detected by both: it is necessary to consider the curve defining the lower limit of vertical coverage for a target of given cross-section at a given range; the scan rate of the antenna and the speed of the target; the role of the radar, probable levels of operator vigilance and the area of a controller's responsibility, and so on. Wherever approximate implied altitudes can be inferred from plotted target ranges and the probable radiation patterns of the radars concerned, the probability of concurrent detection is found to be low, in the sense that the high-speed Bentwaters tracks (for example) would yield only two or three widely separated paints on the CPS-5, and even noticing them in a relaxed ATC environment with "little or no traffic" would be a matter purely of luck. Furthermore, this result assumes a simple linear projection of the observed tracks beyond their points of final contact: over the actual observed track lengths none of the reported targets are well placed for concurrent detection by the CPS-5. Lakenheath's CPN-4 would have stood a better chance due to its high scan rate - but the GCA trailer was not even manned until the action began later at Lakenheath. Bentwaters' chances of observing the interception would be very slim except possibly at high altitudes, and if returns near the CPN-4's maximum range were intermittent or non-existent, it would not be surprising; whether or not the GCA unit was even manned at this time is unknown, as is the completeness of the subsequent report from that unit. Neatishead's role was different from either of the other two installations; charged with defence of the UK their concentration, as the Chief Fighter Controller points out, was on possible inbound targets to seaward, and until alerted by Lakenheath they would tend to ignore traffic inland. When this alert came, the target was immediately found. [19]

Klass's analysis made no attempt to interpret the nature of this target in detail, although it was suggested that some of the events observed at Lakenheath were the result of a faulty MTI which could under certain circumstances generate spurious signals. That the MTI was faulty was suggested by the fact that the target was still displayed whilst apparently stationary, although the MTI circuit should have filtered it out. In fact, the resolution of the PPI is not sufficiently fine to discriminate between stationary targets and targets moving in a small area: a target orbiting or moving back and forth at a speed of about 40 knots or more will be in principle indistinguishable from a stationary target. In practice, the limited persistence of the excitation of the tube phosphor (no more than a second or two) does not allow target positions to be compared with great accuracy from scan to scan, so that the practical limit of detectable motion is higher still. In addition to these arguments, it is also true that a rapidly-rotating body, although genuinely stationary, could return phase-shifted signals which would defeat the MTI filter. MTI faults could not explain concurrent observations by Lakenheath GCA radar, as Klass well knew, which is why his analysis all but suppressed the existence of this installation. Nor can they explain a correlating target detected by Neatishead GCI (which, to remove any possibility of independent coincidental faults, was not even fitted with MTI).

The centerpiece of Klass's study was his deduction that the interceptor pilot was alone in a fighter designed for two, trying to fly the plane whilst simultaneously grappling with unfamiliar radar equipment across the width of the cockpit. This hypothesis, which has been quite widely accepted, rests on a few phrases spoken by the pilot as recalled by the Lakenheath ATC Watch Supervisor: principally, "I've got my guns locked on him" and "clearest target I've ever seen on radar." Klass argues that because the pilot does not refer to a radar operator and uses the first person singular at all times, he could have been alone, a possibility also suggested by his apparent reference to a radar lock-on, since the APS-57 AI radar did not have a lock-on facility. If, then, the pilot were struggling to operate the radar (which would be difficult even to see very clearly) without a proper understanding of its capabilities and limitations, the value of his reported radar confirmation of the target is very doubtful.

However, pilots always use the first person singular (the "royal 'I'", as it has been rather well described) and, having a proprietorial attitude to their aircraft, will not say "we" just because somebody else happens to be in the next seat. Furthermore, the interpretation placed on the recollected words of an English pilot by American personnel may not be entirely reliable. In any event, it is virtually certain that the radar operator was on board: to fly at night on an operational intercept without him would be futile

and suicidal, and that Operations would ever scramble a plane with half a crew (unless all seven other crews of 253 Squadron on standby night duty at Waterbeach that night were struck down) is inconceivable.

Many other aspects of this case could be discussed, but the final word must be reserved for the most serious apparent conflict of evidence, which concerns the control of the interception. Strangely, both the RAF Fighter Controller and the USAF ATCC Watch Supervisor (the latter supported by information in the 1956 intelligence report) are convinced that the interception was under their control. The Watch Supervisor recalls supplying vectors to the aircraft, recalls receiving some brief transmissions from the pilot and recalls hearing an air-to-air conversation between the two Venoms after Venom-number-one broke off the engagement. The AFR 200-2 report compiled by Lakenheath GCA and intelligence personnel soon after the event agrees that the Venom was "vectored to the target by RATCC." The RAF Controller, on the other hand, denies that any part of this was possible, and for what seem to be very good reasons: this was, after all, an RAF interceptor under RAF control; interceptions were Neatishead's job; the RAF GCI regime of the 'fifties was the very paragon of discipline with very tightly defined restrictions on radio traffic, highly confidential R/T frequencies and a private jargon of codewords; and lastly, the Controller remembers quite clearly what the pilot did and did not say. No air-to-air transmissions were monitored, according to this version, and the only transmissions from the pilot of Venom-number-one were the codes: "contact", "Judy" (meaning that the radar operator had the target dead to rights on his own scope and required no further assistance from GCI), followed by the words: "lost contact - more help" after the target was seen to circle behind the Venom. Is it possible to reconcile these contradictory accounts?

The answer is that by making the not-unreasonable assumption that the military authorities perceived a highly unusual situation to exist, all the pieces of the puzzle fall quite naturally into place. First of all, let us ask whether it is likely that Lakenheath RATCC was using the Neatishead GCI frequency. The RAF Fighter Controller's published statement in 1978 [16] argued stridently that this was "impossible" since only the interception team would know this frequency. Subsequently [17] he stated that he believed a request for this frequency was received, but the Lakenheath Watch Supervisor's statements [3,18] make no reference to such a request or betray any awareness of the existence of Neatishead GCI, which suggests the possibility that this request came from elsewhere. It does indeed seem unlikely that the RATCC team supervisor, a sergeant in the USAF Communications Squadron, would himself have the authority to initiate such liaison with a secure RAF facility even had he known who to call, and equally unlikely that the Chief Fighter Controller would pass this highly confidential GCI frequency to an unknown air traffic controller over the 'phone without instructions from higher authority. So wherever this request originated, another agency must have been involved, higher up the chain of USAF command and in liaison with RAF authorities. It seems that monitoring the GCI frequency was deemed desirable at some level, but Lakenheath may have had a rather different role to play for the reason that the GCI frequency could not operate effectively as an open communications channel. The GCI regime is not at all concerned with gathering intelligence; its function is simply to guide an aircraft efficiently onto the tail of its target with the bare minimum of talk for obvious security reasons, so conversation would not be desirable or even possible through the GCI system. Thus, although GCI communications would have priority during the interception, if higher authorities wished to query the pilot or passively receive real-time intelligence on the "UFO", another frequency could be assigned which would be available for use at the pilot's discretion as and when the changing situation permitted. The natural destination of any such transmissions would be Lakenheath, for there the controllers had been working with the target for some 50 minutes before Neatishead was even alerted and a conference line had been established, with USAF and RAF authorities hooked into the supervisor's switchboard. Thus, communications to Lakenheath would not be for the benefit of the curiosity of USAF radar personnel, but would feed through Lakenheath directly to this conference line. There is thus a rational motive for such an arrangement, and whether Neatishead would be informed would be entirely a question of their "need to know". In view of the necessarily circumscribed role of the GCI facility and the parsimony characteristic of British military intelligence, it seems unlikely that Neatishead would be deemed to have a need to know.

Having established a motive, the key to the means is the Venom NF2a's R/T system, which consisted of two VHF transmitter-receivers each with its own 10-channel controller providing a total of 20 pre-set frequencies between 100 and 156 MHz. Channels could be selected by a rotary knob, and the VHF unit in use could be selected by a simple spring-loaded switch near the pilot's left hand. To talk out, the pilot or radar operator must depress a press-to-transmit (P-to-T) switch which opens a circuit to the chosen VHF unit. Unless this P-to-T switch is closed, the aircraft is dumb. Similarly, if one VHF unit is switched in, the other is switched out, and on the latter's selected frequency the aircraft is again dumb, and if the control knob is rotated to a different channel the same applies. In other words, neither Neatishead nor Lakenheath can distinguish between the P-to-T switch being released and transmission being switched either to the other VHF unit or to a

different frequency on the same unit. The aircraft can talk to either ground station without the knowledge of the other. Furthermore, and most important, Lakenheath cannot tell when the aircraft is listening to them, when the aircraft is listening to GCI, or even whether the radio on the aircraft is switched on at all. Thus having no need to know the details of RAF interception procedures, the personnel in the ATC radar room at Lakenheath would have no reason not to assume that, having once been in radio contact with the aircraft, they remained in contact during the intercept. The pilot, meanwhile, would now be following instructions from his controller at Neatishead, deaf to vectors that might from time to time be supplied by Lakenheath but appearing to respond by obligingly closing on the target.

By what means might such an arrangement be set up without radio contact through Lakenheath or Neatishead when the aircrew would be sitting in the aircraft at the Waterbeach operations readiness platform throughout the night "ready to push the starter button"? [19] The Venom had a confidential telebriefing facility, a port in the tail boom which connected the pilot to the operations briefing room by a secure landline which disconnected automatically as the aircraft taxied away. Mission instructions given in this way could not be accidentally compromised because the activation of the telebriefing line automatically disconnected the VFH units. Indeed, so secure are mission instructions considered that the Squadron Operations Records Books, which contain details of the briefing given to the pilot that night, will not be transferred to the public archive until the year 2031! [20]

If the motive and the means have been established, what about the opportunity? Does this scenario work in detail to make sense of the sequence of events as reported? The RATCC Watch Supervisor stated that on first radio contact with the Venom he relayed details of the target's behaviour, its possible altitudes and the report received from Bentwaters - "all the background information." This initial transmission appears definitely to have been acknowledged. After the interception, a brief conversation was monitored between Venom-number-one and Venom-number-two as the latter was approaching the area; number-two also spoke briefly to Lakenheath before returning to Waterbeach. Let us look first at these two phases of the incident, which the RAF Controller insists did not occur but which are at least partially substantiated by the contemporary intelligence report.

According to the Watch Supervisor, radio and radar contact with the Venom were established 30-35 miles SW of Lakenheath (although Waterbeach is only 20 miles SW - he explains this by pointing out that the aircraft would take off to the SW as usual into the prevailing winds, consuming 10 miles or more executing a climb and turn to the NE [18]). The range of the aircraft from Neatishead at this time is therefore 70-75 miles, and the fact that radio contact with Lakenheath was only established at this time raises the question of whether radio contact with Neatishead would have been possible. The main factor here is the aircraft altitude: at 10,000 feet the VHF radio would have a maximum range of about 100 miles air-to-ground [21], but at lower altitudes this range would drop, and the fact that radar contact was established at this time fixes the aircraft altitude (according to a best-estimate of the low-level coverage of the CPS-5 and the Watch Supervisor's altitude estimate based on experience) at between 2000 and 3000 feet. It is thus very probable that the aircraft would not be in contact with Neatishead GCI until it had gained further altitude or closed range, and at this time one would expect the pilot to take the opportunity of talking to Lakenheath.

At the time of the radio contact with Venom-number-two and the air-to-air conversation reported by Lakenheath, Neatishead had stopped painting the target and officially released the interceptor from its mission. Thus the explanation for the absence of such a conversation from the RAF Fighter Controller's account is simply a question of timing: at this time the interceptor was no longer under the control of GCI and was not talking on their frequency. For Neatishead, the incident was already over. Venom-number-two was in all probability not yet within range of GCI: note that the Watch Supervisor recalled - "he was not on radar at this time, probably had just taken off and was too low for us to pick him up, or too far away - we had most of the scopes on short range so we could watch the UFO closely..."[3]. "Short range" would be in the region of 30 miles, since the area of the action at this time was within 10-30 miles in the southerly sectors from Lakenheath.

Now we come to the main phase of the interception proper. The sequence of events reported by the Watch Supervisor (and the intelligence TWX to several USAF commands in addition to Blue Book) is that after a period with no reported acknowledgement from the Venom, during which it was closing on the target, the pilot called Lakenheath when the target was at about 12 o'clock, 2600 feet and reported: "I've got my guns locked on him". As the Watch Supervisor recalled this message it was prefaced with: "Roger, Lakenheath...", in apparent acknowledgement of RATCC instructions. The intelligence TWX simply states: "pilot advised target was on radar..." It does not seem unreasonable that, given the role RATCC personnel believed themselves to be playing, the Watch Supervisor could interpolate the word "Roger" in his recollection twelve years later. Now during this period the Venom was in contact with GCI twice: once reporting "contact", then shortly afterwards the code "Judy". "Judy" means that no further GCI assistance is required because the radar has a firm target, and so from this moment the pilot is not listening to his controller. He is thus free in principle to switch his frequency to that of

Lakenheath, and although the RAF Controller points out that at this time both pilot and navigator would be "concentrating hard" on target position data being read over the intercom, it perhaps overstates things to describe the words "I've got my guns [locked] on him" as "nattering to Lakenheath." [17]

We thus have the pilot reporting "Judy" then leaving the GCI frequency. Immediately on switching to Lakenheath's frequency the pilot reports the situation in a few words. This transmission does not interfere with last-minute range data from the radar operator since the operator can at any time interrupt - the intercom link is opened by depressing a press-to-mute footswitch which simultaneously disconnects the VHF receiver. Since the target is now dead ahead at 12 o'clock and within range of the Venom's four 20 mm Hispano cannon, the only radar information coming over the intercom will be range updates, but in fact it is doubtful whether the radar operator would have had time to begin counting down the remaining 2000 feet of range since the target was almost immediately lost.

According to the RAF Controller, after the pilot reported "Judy" only a "few seconds" or "one or two sweeps on our scopes" (10-20 seconds at 6 rpm) elapsed before the object had looped round and got behind the Venom [16] in a manoeuver which was interpreted as a positive-gee loop up and over the aircraft but which could equally have been a negative-gee loop below the aircraft (the Controller was watching a PPI monitor remoted from the interception cabin consoles and had no altitude information available). The SCR 720 AI radar had operator selectable elevation tilt limits between -20° and +40°, and a manoeuver with a downward velocity component of only 100 mph would take the target out of the radar coverage beginning from O° relative elevation in a little over two seconds at 1000 feet range. A target moving at the speeds reported by ground radar (600-800 mph) could disappear from dead-ahead in less than 0.4 sec at this range. (Under full power the Venom would close with the stationary target at a rate of about 750 feet/sec, so this range would be reached about 2 seconds after Lakenheath reported the target at 2600 feet, 12 o'clock from the aircraft). Again, if the target completed its loop in 10-20 seconds after the pilot reported "Judy", it would be lost from the AI radar's forward elevation coverage in a small fraction of this time. (A travel of 180° in 10-20 seconds implies an angular speed of 9-18°C/sec, corresponding to a vertical velocity of 100-200 mph at 1000 feet range neglecting accelerations). It seems consistent with the report from GCI, then, that the target was lost almost immediately after the pilot left the GCI frequency and therefore at about the very moment he was speaking to Lakenheath, which is also consistent with the Watch Supervisor's statement that the pilot had just reported that he had his guns on the target "then he paused [this would be the radarman interrupting the VHF link to report signal loss over the intercom] and he said, 'Where did he go? Do you still have him?'" Lakenheath answered that the target was now behind him.

It would be at this moment that the pilot would decide he needed more help from his controller and would switch back to the GCI frequency. This he did, calling "Lost contact - more help." He was told by GCI that the target was now behind him and given fresh instructions to evade his pursuer. [16] GCI would give him not only target range and bearing more accurately than Lakenheath but also altitude data which Lakenheath was not equipped to supply. This transmission is the answer to a question which has exercised the ingenuity of several commentators, notably Klass: that is, when the pilot next contacted Lakenheath and was able to "confirm that this [circling] had occurred" (according to the Watch Supervisor and corroborated by the intelligence TWX), how did the pilot *know*, when the Venom has no tail radar and restricted rearward visibility? The answer, of course, is simply that he knew because he had checked with Neatishead GCI.

During the subsequent chase, which lasted from 5-10 minutes, the pilot would be free of the need to concentrate on instructions from his radar operator since the target remained behind the Venom and the AI radar was redundant. At this time he would be at liberty to report the situation to Lakenheath, GCI communications permitting. It is doubtful that he would have much attention to spare, however, and under these circumstances it is consistent that his words to Lakenheath were reportedly "occasional" and "scared". After 5-10 minutes GCI had lost the target from their scopes due (it was believed) to a swift descent out of the radiation pattern, and the interceptor was released from GCI control. Two brief radio contacts with Lakenheath occurred as the CPS-5 continued to track the target in the vicinity (or apparent vicinity - relative altitudes being unknown) of the homeward-bound Venom for "a short distance." The second Venom then called Lakenheath on the same frequency, the target meanwhile having stopped and proceeded north at 600 mph to eventually leave the radar coverage at about 50-60 miles range.

The above construction of events is conjectural but it is entirely self-consistent and makes sense of what might otherwise appear to be serious anomalies. To this extent it is a good hypothesis, although at present security restrictions prevent it being tested against information in official records currently held by the Air Historical Branch of the Ministry of Defence in London and, presumably, US security agencies. Notwithstanding some uncertainties, however, the Bentwaters/Lakenheath/Neatishead events are today, three decades on, probably the most impressive of their kind on record.

CONCLUSIONS AND RECOMMENDATIONS

None of the cases here discussed is free of ambiguities, information of uncertain reliability, the frustrating absence of key details, and the same could be said of the many other events which one would like to discuss. In even the best documented cases there remain dark corners that future researchers will probably never fully illuminate. Nevertheless, events such as those we have dicussed are, *prima facie*, suggestive of the existence of tangible aerial phenomena escaping any current scientific classification insofar as the available data fail to convincingly support any other view.

In each of the cases discussed here, an explanation could be given if one were permitted to ignore or modify key items of testimony on the basis that nothing could be less likely than a "real UFO" (whatever that might be); after all, we know that errors occur - we do not know that UFOs do. Nevertheless, such an approach is at best *ad hoc* and open to the charge of being more sophistry than science. The most that can reasonably be done is to attempt to find collateral evidence, perhaps latent in the statistical population, that such a procedure would be justified; however, the reliability of statistical inferences is difficult to assess when the total available population is small.

In summary, the statistical properties of the limited sample considered are ambiguous, although there is some suggestion that the circadian distribution of the sample may correlate with the development and decay of atmospheric stratification responsible for anomalous propagation. It may be relevant to note here that *in general* visual sightings associated with radar-UFO events are of low to medium definition.

A number of events, however, are extremely difficult to interpret in terms of AP or other conventional phenomena. Some events involve targets whose duration, consistency of strength, continuity of behaviour and (in a few cases) apparent reaction to the environment suggest an unclassified airborne physical "object" as the most straightforward interpretation. That is to say, if such a phenomenon were consensually available, in the sense that phenomena such as AP, balloons and "ball lightning" are available, then it would reasonably be regarded as the most probable cause of these events.

The phenomenon's characteristics would include flight capabilities ranging from hovering to supersonic speeds, rapid accelerations and high rates of climb. It would be a reflector at radio (and possibly optical) wavelengths, and an emitter at optical wavelengths (though not always). Optical emission would typically be incoherent white light, though blue and orange are occasionally reported. Cases exist which would seem to require a phenomenon which is not always an optical reflector: ie Colorado Springs Airport, Colorado, May 13 1967, where surveillance *and* precision approach radars tracked an inbound target low over the field at 200 feet in daylight and fair visibility although neither a following flight nor control tower personnel with binoculars could see anything. [3] This case, described by Thayer as "one of the most puzzling on record", is unexplained.

Fusion of two or more targets below the limit of PPI resolution is sometimes reported, as is fission of larger targets into "elementary" targets. Radar cross-section would be variable, with an elementary target typically approximating that of a small jet fighter or smaller. Generally speaking, the targets observed in the most interesting cases behave in a remarkably versatile but not supernatural or irrational way. It seems likely that some of the capricious extremes of behaviour (occasional sudden disappearances, for example) could be explained by the normal imperfections inherent in radar systems and their propagation environment.

Visual sightings are typically of round white or blue-white lights with a small but sensible angular extension. Fission or fusion of two or more lights is sometimes reported, and angular rates range from zero (stationary) to many degrees of arc per second. An impression of non-inertial manoeuvrability is sometimes conveyed. In general, visually reported behaviour is at least qualitatively similar to that displayed by radar, and there do appear to be cases in which the radar-visual correlation can be considered good.

The fact that the radar-UFO file is dominated by cases from the 1950s (which is not to say that startling events have not been reported since) may be explained by a lower false alarm rate in modern radars and an increased understanding of the complexities of the radar environment. However, it could also reflect other factors such as the effective closure of the military record since the mid-sixties, the increased use of SSR radars and the development of clutter-rejection systems. Most of the older radar cases involve military radars operated by the USAF and owe their public visibility to the existence of the Blue Book record. Since declassification of the Blue Book files following the termination of the project in December 1969, and their subsequent transferral to the National Archive in Washington DC, a number of previously unknown cases have come to light adding to the number catalogued for the early years of UFO history. Since this date, the only significant information on new military radar events has been obtained with some effort through Freedom of Information suits. In the civil sector the widespread introduction of SSR (Secondary Surveillance Radar) and synthetic displays in recent years has already been mentioned. The very object of this technology is to narrow the field of attention of both operators and radar in air traffic control, increasing the efficiency of aircraft identification and routeing to the benefit of air safety but reducing the probability that

anomalous targets will be attended to. Air traffic, especially in the civilian sector, is an enormously more demanding problem than was the case thirty years ago. The more sophisticated radar signal processing becomes in response to these demands, the narrower the filters - both electronic and perceptual - through which rare phenomena unanticipated by, or actively suppressed by, the system design must pass. One example of clutter rejection which has come into widespread use is non-linear polarisation, which is a rotation of the electric vector of a portion of the output wave causing signals reflected from bodies of a chosen sphericity or ellipticity to be rejected by the receiver. In normal use this technique suppresses returns from hail or rain droplets, but it can be seen that it will prejudice the detectability of other targets with a similar degree of overall symmetry.

Despite these difficulties, a number of intriguing incidents have occurred during the post-Condon era. In the autumn of 1975 a number of radar-visual events occurred in the vicinity of Air Force Bases and missile sites along the northern tier defences of the United States and Canadian Forces Stations across the border. Documentation of these incidents, in which penetrations of weapons storage and other secure areas by unidentified lighted objects were tracked by radar (sometimes multiple radars), was obtained with some difficulty by Citizens Against UFO Secrecy (CAUS) through FOI requests. A compilation of this fragmentary material by Fawcett and Greenwood [24] does not permit detailed analysis, but it is clear that the security reflexes of the USAF were jolted by these incidents, of which a number are clearly not AP-related, and it would appear that UFOs remain a problem - though now a private problem - for the military intelligence community.

On 19 September 1976 a multiple radar-visual event near Teheran, Iran - [see also Section 2.3, Case 12] - prompted a report within the US Defence Intelligence Agency (DIA) describing an interception by F-4 Phantoms of the Iranian Air Force of an "object" at 25,000 feet with a rectangular pattern of strobing coloured lights. Both F-4s reported weapons-control, INS and communications failure in its vicinity. Radar lock-on was achieved with a target comparable to a 707 tanker in cross-section. A smaller object was observed to detach itself from the larger body and force an F-4 into an evasive turn. This object appeared to outperform the F-4. Another object left and was seen to approach the ground at high speed, where it was reported by civilian observers. The UFO, noted the DIA report, was seen by "multiple witnesses in different locations... both airborne and from the ground" and their "credibility was high"; the sightings were "confirmed by radar", electromagnetic effects were reported "by three separate aircraft" (one civilian airliner and the two F-4s), and the brilliance of the object caused pilots to lose their night vision. The manoeuvrability of the object was "inordinate". The DIA evaluation of the case information characterised it as "unique, timely and of major significance." Only a fragment of the documentation believed to exist on this case has been obtained by FOI requests in response to initial newspaper reports. [24]

Observations of unidentified radar targets continue to occur in the decade of the 'eighties. Whilst we are not close to understanding the nature of some of the most puzzling events, a great deal more is known today about the value and limitations of this type of evidence than was the case in the innocent days when any uncorrelated return could become a "flying saucer". Attitudes to the evidence are more sophisticated and radar theory itself is more advanced. But a great deal remains to be done. Recommendations for future research would range from exploring the design of dedicated systems, instituting short- or long-term monitoring projects with existing instruments in areas of high report density, and saving data from routine civil or military radar operations, to consolidating the existing data-base for the purpose of effective statistical analysis.

Defence and space surveillance radars are highly dedicated systems in which huge numbers of uncorrelated (though not necessarily anomalous) targets are dumped irretrievably by the software. Suggestions have often been made [eg.25] to the effect that sub-routines could in principle save anomalous data from disposal, but the information content may be low [26] and there may be a conflict of scientific and defence interests. The development of UFO-dedicated radar systems with signal processing tailored to favour targets with certain parameters (presumably derived from analysis of the existing data-base) would be perhaps worthwhile, but the cost would obviously be prohibitive without funding of a kind it is unrealistic to anticipate at the present time. Monitoring projects using existing radars have actually been undertaken on various scales. In the autumn of 1967 investigators from Colorado University, Stanford Research Institute, Environmental Science Services Administration and other bodies visited an Air Force Base in California to study anomalous targets being reported intermittently on tracking and search radars. Targets were observed by the investigators, who were able to attribute them to anomalous propagation and birds detected due to the sensitive tracking radars being used in a search role for which they were not normally used. [2] A full-time UFO monitoring facility, Project Starlight International, was set up near Austin, Texas, in the mid-seventies. [27,28,29] A short-term monitoring project was undertaken in the Hessdalen Valley, Norway, in January and February of 1984 following a dramatic increase in the incidence of reports from this area. This enterprise received support from the Universities of Oslo and Bergen and attracted the co-operation of the Norwegian Defence Research Establishment. Thirty-six radar tracking incidents

were recorded over a five-week period. One target, which was simultaneously observed visually and filmed as a continuous light source, reportedly gave paints on the radar only on alternate sweeps, an oddity for which no immediate explanation suggests itself. The data, however, have yet to be fully digested. [30]

Parallel with such activities, it is important to work with the data already available. Geographical, seasonal, circadian and other distributions should be studied in relation to propagation conditions conducive to false echoes. The existence of previously unsuspected atmospheric structures should not be ruled out, and the study of radar-UFO events may lead to new knowledge in this area. Phenomena related to ball lightning or other atmospheric electrical effects should also be considered as a possible explanation of some anomalous targets. The high *prima facie* strangeness of some events, however, argues that the search for still more exotic hypotheses could yet bear fruit.

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