Anomalous Echoes Captured by a B-52 Airborne Radarscope Camera: A Preliminary Report

(Part 2)

Martin Shough

5. Reconciling Time and Distance Data

Knowledge of the positions and altitudes of the B-52 at the times when the radarscope photos were taken is important, both for interpreting the display indications and for the overall coherence of a reconstruction of events. The clock, the frame counter, and a time-flagged transcript of RAPCON radio communications, together hold out the promise of precisely cross-correlated events in this case. There are some unexpected problems with this, however, and it becomes important to be able to check the consistency of our reconstruction against internal evidence recovered from the radarscope photos.

Firstly let us consider the solitary sector scan which we have tentatively identified as frame 784 and where the radar system status is encoded in an array or "plaque" of 6 data lamps as shown in *Fig.5, Section 5*. It is possible to verify that the pattern of lamps on frame 784 fits only one configuration of this array, identifying the following mode of the radar:

Range scale:	20 NM
Hand Control (DeadmanSwitch):	ON
Memory Point:	OFF
Scan direction:	CCW

The function of the Deadman Switch is uncertain. The scan direction indicates that the camera was triggered at the end of the counter-clockwise trace rotation. The Memory Point is not discussed in available documents, but presumably this is the PDI or Position Direction Indication that McCaslin recalled using to fix the UFO "landing" point so that the navigation computer could automatically bring them back to overfly it after their first go-around at Minot (although in fact the go-around could not have taken the B-52 within several miles of this location). The Memory Point is "off" here as a default, but is engaged by the navigator depressing a single switch.

The 20 NM range scale makes the radius to the edge of the first ground return more than 5 NM. But given the known altitude of the descending B-52 as at frame 783 (see *Section 5ii* below) this is hard to understand in terms of any listed mode of the radar. It is also disquieting that the radius of the hole as seen on the tube appears almost identical to the altitude hole radius on frame 783, an uncomfortable coincidence given a changed range scale.

It has been suggested that the navigator switched the radar into Independent Bomb Damage Assessment (IBDA) mode to scan aft of the B-52 when the target vanished. This makes practical sense, and switching to IBDA mode would enforce the change from 5 NM to a longer range scale (for the obvious reason that bombing altitude is over 20,000 ft) ; but this automated mode enforces an off-centre sector scan *ahead* of the aircraft when first entered, which then changes to a full PPI scan at 20 NM, and *not* a sector scan, after bomb drop. Terrain Clearance mode also enforces a sector scan ahead of the aircraft, for obvious reasons. (The hypothesis that frame 784 should be inverted, showing a forward sector scan 24 degrees either side of an a/c heading of about 308 degrees, was rejected because the camera data lamps then become unintelligible.)

In a recent interview, Richard Clark, the Bomb Wing intelligence photoanalyst who originally had the set of prints made in 1968, recalled that this sector scan photo probably preceded frame 771. This implies the possibility that it shows a Ground Map mode entered near the start of the incident when the plane was at higher altitude (near 20,000 ft MSL). In this mode the display is *altitude-compensated* so that the >5 NM radius to the edge of the first ground echo is not slant range, but true ground range from the nadir to the heel of the beam. But according to CDC 32150K, Vol.4 this radius is automatically kept at 3NM in this mode, not >5 NM, and the coincidence of the similarity between the measurements of the actual 783 and 784 PPI images remains uncomfortable.

In the end it is impossible to definitely identify the radar mode in this sector scan frame or to be certain when it was taken so it is of little help to us. Fortunately, for the remaining 13 frames the radar mode not is in doubt, allowing us to extract useful information. This may help to remove or reduce ambiguities in the reconstruction of events that documents and witness statements are unable to remove.

As mentioned earlier it appears that we have only around one tenth of the radarscope photos originally taken. Richard Clark, the 5th Bomb Wing Intelligence Officer who examined the original negative film in 1968 and personally ordered the prints made, recalled that there were probably "over a hundred" frames in addition to the 14 (including the anomalous frame #784) that he ordered printed up. This total *could* be consistent with the camera having been switched on close to the beginning of the incident (39 NM out according to the official file) and left running through to the end of the incident about 14 NM from Minot runway, which would have generated in the region of 120 frames in total.

According to Clark's recollection, the 13 consecutive frames 771-783 came from the beginning of the negative strip, and the sequence 771-773 records the initial high-speed approach (as it was construed) of an unknown target and its motion from the right to the left of the scope where it began to keep station on the B-52. In general, the positions of the echoes on the photos appear to be somewhat similar to the way this behaviour is characterised in the earliest official report. But at the same time there is contemporaneous documentary evidence suggesting that the photos were taken near the end of the incident, and also the match between the above scenario and the photographed target kinematics is not without anomalies, in particular, consistent evidence that the initial right-to-left transit by the echo occurred during a wide radius turn near the TACAN approach beacon. The photographed heading marker shows no evidence of a turn. So questions remain. The first question to address is whether the scope photos reveal any internal evidence of the map location of the aircraft.

Attempts to investigate this issue have been made by the twin routes of *i*) matching ground echo features against topographical maps of the area, and *ii*) determining the aircraft altitude from the photos for comparison with known elements of the approach path. The results of *i*) are inconclusive (excepting some recent work by Claude Poher discussed below), and the results of *ii*) invite real doubt that the extant photos can have been taken at or near the beginning of the UFO episode.

i) Ground features

Attempts to correlate some apparent ground echo features with local topography were begun by Jim Klotz. This work will not be discussed here. The present section is limited to describing a few apparent ground echo features which should probably be excluded from the mapping attempt. Investigation suggests they are blemishes of some kind.

Feature #1: This feature is visible on all scans as a dark mark against the speckles of noise or ground clutter just inside the 1.75-mile range ring at ~92 degrees azimuth. Early impressions were that this was a lake. Bodies of calm water tend to specularly reflect radar energy away from the antenna, unlike rougher ground textures which scatter energy back to the antenna, and do appear as "negative" returns against bright ground echo. However close inspection reveals anomalies:

Firstly, measurement of the indicated bearings shows that the feature does not fall aft of the B-52 heading as would be expected, indeed it *advances* a degree or two in the direction of flight; secondly on frame 777 the same dark mark can be seen partially occulting a bright blip (a possible unidentified echo, but appearing only for one scan) with a fairly hard edge, in such a way as to suggest an obstruction either on the glass or near the camera film plane; and thirdly, and most importantly, a similar mark appears on frame 771 in the same position, even though this is in the half of the radarscope that has yet to be written on, the first complete sweep rotation having not reached that part of the tube (see *Fig.6* below).

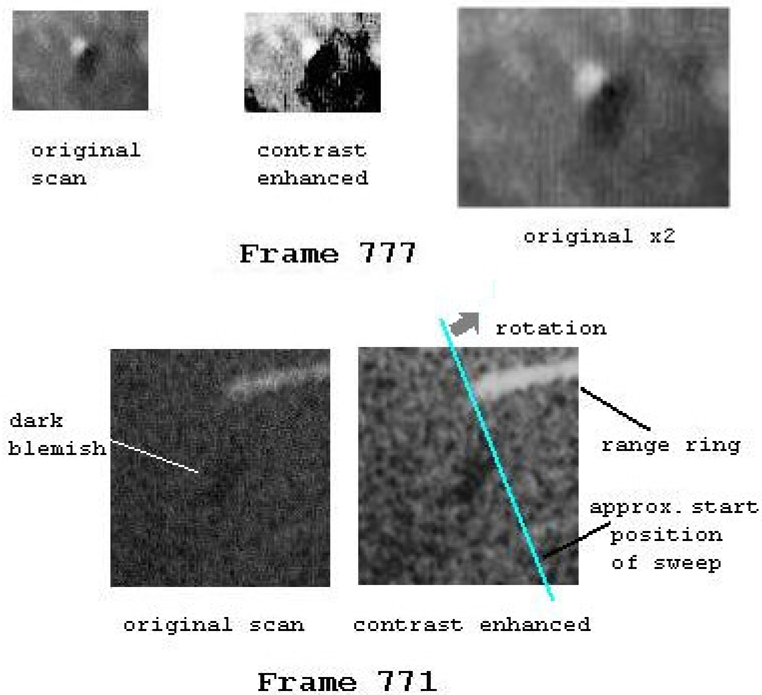

Fig. 6. Details of Feature #1 from frames 771 and 777

Features #2 & #3: These are two small dark features in the bright ground echo behind the plane, at first glance resembling negative returns from small lakes or ponds, of which there are many in the area (see *Fig.7* below). However to check this resemblance all the displayed ranges to the most distinct of the pair (Feature #3, @ ~312 degrees) were re-measured as closely as was practical. The results are tabulated below.

FRAME #	mm from alt.hole	mm from centre spot
771	n/a	n/a
772	57	170
773	60	169
774	61	168
775	62	167
776	63	167
777	65	166/7
778	66	166
779	66	165
780	68	164
781	70	165
782	72/3	165
783	75	165

Table 1. Radial distances in *mm* from the inner edge of Feature #3 to the outer edge of the centre spot and to the edge of the altitude hole.

(An effort was made to estimate the nearest mm; however the edges are blurred, so there is some uncertainty. Measurements were made with a steel rule on the computer screen, with each image in the same position on the screen to eliminate possible distortion.)

Evidently the distance from the "lake" to the edge of the altitude hole increases over time (the hole shrinks inward from ~2.1 miles radius to ~1.8 miles, presumably because the plane is descending whilst the vertical coverage angle stays fixed) as one might expect. But the distance from the centre spot fairly systematically *decreases* even though the aircraft heading (132 degrees) is almost precisely opposite the bearing to the "lake" (~ 311-312 degrees, this hardly changes detectably). In other words the slant range to the "lake" aft of the aircraft actually decreases by about 428 ft in 33 seconds, or it exhibits a closure rate of 778 ft/min = roughly 8 knots.

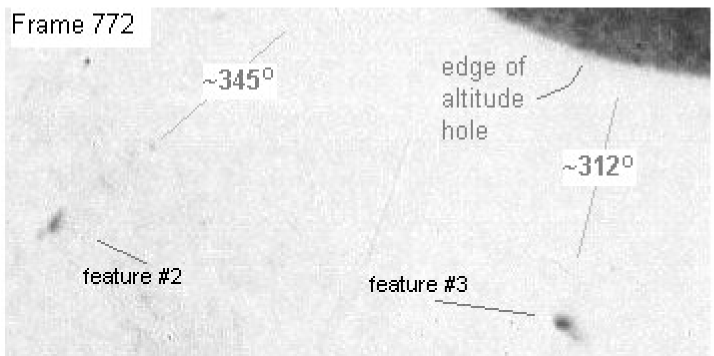

Fig.7 Detail of Features #2 and #3 from frame 772

Obviously the slant distance to a stationary lake should change like the vector sum of the plane's forward motion and its rate of descent. The contribution of the descent will indeed be negative, but very small compared with the positive forward velocity (~250 mph), for any angle of descent smaller than about 45 degrees or so, even at the highest possible altitude of the B-52 (20,000' MSL), and reduces rapidly at lower altitudes. The real situation - deduced from the photos, the equipment characteristics and the probable approach path (see below) - appears to be that the aicraft's angle of descent and altitude are around 1/10 and 1/2 respectively of the above values, so we conclude that ground features could not reduce in displayed range as do Features #2 and #3.

If the measured displacement of the objects is not consistent with ground features, the question remains as to why they do change apparent position at all. This remains unexplained. The unlikely hypothesis that they are flying objects with efficient stealth characteristics (see also *Section 6.b* below), appearing as "holes" in the bright ground echo, was considered but rejected after close examination of frame 771. As was found in the case of Feature #1, a small dark mark can be faintly discerned in the position of Feature #3 at ~312 degrees, again in the part of screen on which the rotating trace has not yet written. This appears to prove that Feature #3 is an artefact of a similar kind. (The same test is inconclusive in respect of the fainter Feature #2.)

Feature #4: Another class of markings will be collectively named Feature #4. As in other cases, the same or a very similar feature is found on a number of frames, particularly 771, 776, 779, 781, 782 and 783, a relatively bright line generally running vertically from about 90 degrees to about 328 degrees with very small variation. It has been suggested that this indicates a highway. However close examination shows that a faint continuation of this feature can be traced extending beyond the tube face in some instances, crossing the bearing ring and onto the instrument fascia as shown in *Fig.8* below. On certain frames parts of the feature resolve under magnification into what appears to be a complex of tiny abrasions. The approximate position on the negative appears to be the same in most cases, and the orientation aligns parallel to the edge of the negative strip.

Fig.8 Detail of Feature #4, frame 771

One inference would be that the original film roll was scratched at some stage, possibly in the camera feed mechanism or when when being spooled through the viewer at Minot. But the positive print image of such a scratch ought to be dark, of course, not bright, unless the prints were made from an intermediate contact film positive which was itself damaged in this way, in which case the prints would be negative images. They are not. If there was no interpositive film stage in the production of the prints then we are left with scratches on the enlarger slide or the glass of the print frame, which both seem very unlikely since the marks would then have the same appearance in roughly the same position on all photos, and they don' t. So how these apparent abrasions got there remains a small mystery.

In summary, several promising ground features are removed from consideration by this analysis, leaving one convincingly lake- or river-like serpentine feature on frame 783 as almost the sole point of reference for a topographical match. The likelihood that this will prove sufficient to fix the aircraft location appears small, but in combination with a second approach it might still be valuable. We turn to this next in *Section 5.ii*.

ADDENDUM: A recent computer analysis by Claude Poher has indicated a pixel-level correlation between a part of this frame 783 feature and a part of the W shoreline of Lake Darling. If this is reliable then it places the B-52 about 5 nautical miles or more back from any position indicated in the contemporaneous documents (including the Base Dispatcher's concurrent log of events, Col.Werlich's chart of the flight track, TACAN coordinates entered in the AFR 80-17 report, and the copilot's report of position in the RAPCON transcript). There is no clear explanation of this discrepancy. Nevertheless, the figures given in the case documents are themselves not entirely coherent and attempts to find a different topographical match for frame 783 have not so far met with success. Lake Darling appears to be the only feasible candidate less than 5NM (PPI slant range) from the flight track.

ii) Aircraft altitude

Measurements of the radarscope images were interpreted with reference to characteristics of the radar to indicate limits on the possible flight altitude. The results of such an investigation provide quite strong evidence that the altitude of the aircraft is grossly inconsistent with the known altitude at the time the first echoes were reportedly detected. This tends to support the 1968 reconstruction of the incident by Col. Werlich in which these extant photos were taken at or near the end of the incident (some 19-16 statute miles, or 16.5 - 14 NM, from the runway according to his contemporary record).

Accurate altitude determination by this method depends on knowing the depression angle of the bottom edge of the radar beam where it intersects the ground. If we know the depression angle we can calculate the altitude from the displayed slant range. This angle depends on two variables: The tilt angle of the antenna boresight, and the vertical coverage pattern of the beam which is itself a fairly complicated function of range due to the cosec^2 vertical profile (the aircraft orientation is immaterial since the antenna tilt is servo-stabilised by pitch and roll signals from the ASQ-38 computer). Even a simple pencil beam does not have a definite edge, of course; rather the edge is some nominal contour defined in terms of power density, resolution or probability of detection. But in the present case the "edge" has a rather clear operational definition, as that vertical angle from the antenna boresight corresponding to the fairly sharp transition between altitude hole and ground echo on the PPI.

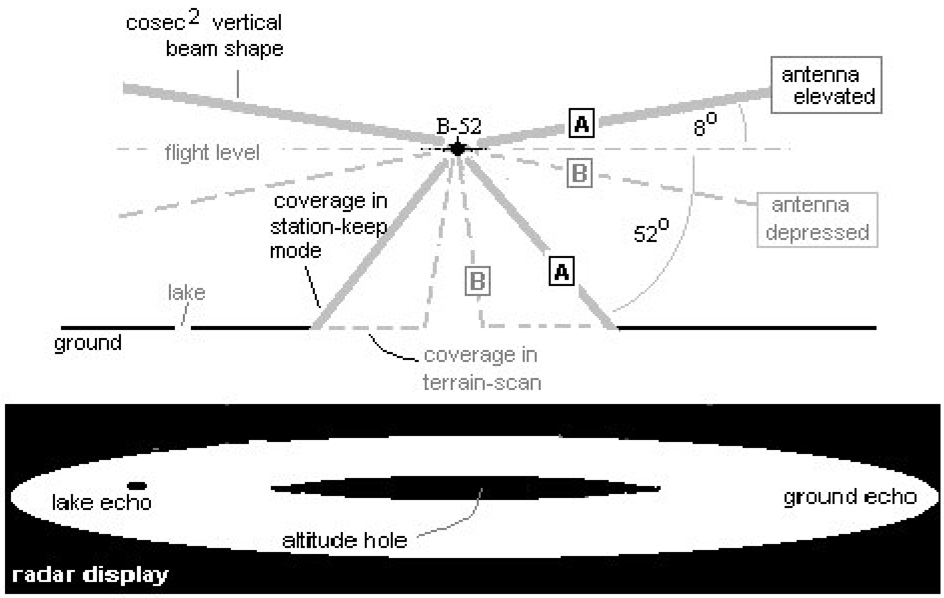

Fig.9 Schematic diagram of vertical coverage and aircraft altitude

In modes designed to scan the terrain (B) the radar operates with the beam depressed, the conical "altitude hole" below the aircraft shrinks to a vertical angle of a few degrees and the PPI shows an altitude-compensated map of true ground range. In Station Keep mode (A) the beam is elevated to detect airborne targets, the altitude hole widens to a cone 76 degrees wide and the PPI shows uncompensated slant range like an ordinary surveillance radar.

The relation between vertical coverage, displayed range and altitude (see *Fig.9*) is simplified by the fact that there is no altitude compensation in Station Keep and the displayed range is simple slant range. This being so the depression angle of the bottom edge of the beam below horizontal is the key to the trigonometry. Training manual CDC 32150K, Vol.4 and the HSBR/IHSBR/ACR Tech Order together indicate that *a*) the vertical beam angle varies from 54-60 degrees; *b*) the angle widens as the antenna is elevated; *c*) in station keep the antenna is maximally elevated; therefore *d*) the angle in station keep is probably 60 degrees; *e*) the training manual gives the top edge beam angle as +8 degrees, therefore *f*) the depression angle is about 52 degrees. [Since it is not certain that *b*) continues to apply when the radar is in Station Keep, it is possible that the depression angle is about 46 degrees. For the moment we continue to assume the former value, but for certain purposes it will be sufficient to adopt a representative value of ~ 50 degrees.] Slant range varies like the sine of this angle and so we can calculate an approximate aircraft altitude.

We can also cross-check this against another inferrable quantity, the *rate* of descent. The true rate cannot be known independently of the true altitudes, but we can use the fact that the altitude hole radius reduces from about 2.1 miles to about 1.8 miles in 36 seconds to calculate some limits and a set of values for a range of radar angles. Since the B-52 was performing a text-book approach to the Minot AFB runway from a known altitude on a pilot evaluation exercise, the various descent slopes consistent with the photo sequence can then be compared against expectation based on two other known data - the average angle of the entire descent from the moment of leaving FL 200 and commencing approach, and the slope of the final glide path printed on the Minot approach plates.

All else being equal (i.e. if the computer-compensated antenna tilt stays the same, as seems to be the case as there are no discontinuous jumps in the size of the altitude hole) then the *slant* range from the antenna to the ground (altitude hole radius) is decreasing at the average rate of ~3080 ft/min during the 36-second photo sequence. Obviously the rate of vertical descent is less than this. The true rate would vary as the sine of the depression angle. Thus for frame 771 (slant range ~2.1 NM or 12,750 ft) and frame 783 (slant range ~1.8 NM or 10,930 ft), we have these illustrative pairs of terminal altitude values (*Table 2*) for different radar coverage depression angles, leading to various average descent slopes for the 36-second photo sequence

radar angle	start alt.	end alt.	rate, ft/min	descent slope
-10 degs	2214	1898	527	1.3 degs
-30 degs	6375	5464	1518	3.9 degs
-50 degs	9767	8373	2323	6.9 degs
-70 degs	11,981	10,270	2852	7.3 degs
-80 degs	12,556	10,764	2987	7.6 degs

Table 2. Radar depression angle and associated descent slope
Altitudes are in feet above terrain

The actual practice approach slope is not known, but according to the Blue Book file the descent over the period of the UFO episode was from FL200 to about 9,000 ft MSL on a ground track of 24 NM, corresponding to an average of about 4.3 degrees. Considering the average slope of the entire approach, from FL200 at 38 NM to 1630 ft MSL at the runway, we find that this would be about 4.6 degrees. Since the final glide slope from the outer marker is known from the Minot AFB approach plates to be shallower than the 4.6 degree average, at less than 3 degrees, one would expect the average angle of descent prior to the final glide slope to be steeper than 4.6 degrees.

There is a deal of uncertainty in these values (we have an ambiguous value for the true range for departing FL200 for example), but crudely speaking they argue the likelihood of a descent slope somewhere near the middle of *Table 2*, about 2000 ft/min at around 5 degrees or so, corresponding to a radar depression angle (*column 1*) somewhat less than 50 degrees. This is not far from the bracketed bottom edge value (between -46 and -52 degs) deduced above from documentation, reassuring us that the basic construction is sound.

Taking 50 degrees as representative of the written specs, therefore, we have these altitude values for the initial and terminal frames of the photo sequence: **9767 ft** above terrain (~ **11450 ft** MSL) and **8370 ft** above terrain (~**10,000** ft MSL), reasonably close to the terminal value of about 9000 ft given by Col. Werlich in 1968.

ADDENDUM: Claude Poher has performed a similar but rather more detailed analysis to find a uniquely consistent model by covarying a number of parameters. Poher' s model incorporates a match between the frame 783 ground echo feature and the shore of Lake Darling, as described in Section 5.ii, and one interesting result is that it requires the distance between frame 783 and the Deering TACAN (by the Minot AFB runway) to be some 21.6 NM instead of the 14 NM recorded in the Blue Book documents. It also requires the depression angle of the radar beam bottom edge to be about -45 degrees. This is some 5 degrees less than the nominal -50 degree approximation adopted here, but would be fairly consistent with the lower limit of the range of possible VPD coverage (54-60 degs) cited in the ASB-4/9 tech order and a +8 degree top edge as indicated in the diagram of the Station Keep field pattern in Fig.3.

Howsoever, the probable terminal values found in Poher' s work are 11498 ft MSL and 9478 ft MSL, quite close (within about 0.5% and 5% respectively) to the values determined here using a different set of assumptions. This coincidence means that it is difficult to choose between the models on some indicators, but happily it also means that interpretations of the unidentified echoes (Section 6) are not very sensitive to uncertainties in the variables determining the model.

iii) Summary and conclusions on time and distance data

As indicated above, attempts to reconstruct a totally self-consistent scenario have encountered problems, partly because of incomplete information but also because of anomalies in the information we have. These anomalies are principally: *a*) timing anomalies and lacunae in the RAPCON transcript; *b*) inconsistent accounts by Col. Werlich of the initial echo behaviour observed near the turn over the TACAN approach beacon at around FL200, >18,000 ft above terrain; and *c*) suggestions that the photo sequence belongs to the initial target behaviour observed near the turn. We will now attempt to use the result of *Section 5.ii* to help resolve some of these problems.

Firstly, *c*) is not only in conflict with Col. Werlich' s contemporaneous reconstruction placing the photos at the end of the event, and with what natural practice would lead one to expect in the circumstances, it is also in conflict with the navigator Pat McCaslin' s independent recall that he did not start the camera until the pilot suggested this some time much later in the event (see *Note 4*). Further, we have now shown that the altitude of the B-52 at the time of the photos is definitely inconsistent with the theory that the photos show the start of the event, but could indeed be consistent with Werlich' s 1968 scenario placing them at the end. As will be shown below, the upper limiting target rates found from the scope photos are also inconsistent with the initial echo behaviour as described by Col. Werlich, although they could be consistent with the rate independently recalled by Clark.

For purposes of discussion it will sometimes be useful to divide the photos into two phases: *Phase A*, frames 771-3, interpretable as the rapid pass and transit of a UFO to a position off the left wing; then a lacuna in 774-5 where the echo (definitely in 774; arguably in 775) disappears; followed by *Phase B*, frames 776-782, the reappearance of the echo stationed persistently off the left wing, disappearing again in 783.

According to Werlich' s early Memo for the Record, October 24 1968:

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Initially the target traveled approximately 2½ mile in 3 sec
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> or at about 3,000 mi/hr. After passing from the right to the left of the plane it assumed a position off the left wing of the B-52. The blip stayed off the left wing for approximately 20 miles at which point it broke off.

There is certainly a similarity between this description and the *Phase A* sequence which shows echoes 1.62 miles off the right nose (#771), 1.05 miles just aft the right wing (# 772), then 1.05 miles off the left wing (#773). See *Fig.12*. But Werlich's "about 3,000 mph" can't be recovered from this photo sequence (see below) and by the time of his October 29 telex Werlich has a different understanding of what the initial behaviour was:

> AFTER ROLLING OUT OF A RIGHT TURNAROUND TO THE TACAN INITIAL APPROACH FIX, A BRIGHT ECHO SUDDENLY APPEARED 3 MILES ABEAM AND TO THE LEFT OF THE AIRCRAFT. THE ECHO RAPIDLY CLOSED ON THE AIRCRAFT AND REMAINED AT ABOUT 1 MILE.

This time there is no mention of 3000 mph or of the target crossing from right to left of the aircraft. Instead we have only a "rapid" closure from 3 miles off the left wing to 1 mile off the left wing. Plainly the photos do *not* show a target 3 miles off the left wing at any time, neither do they show a closure from 3 miles to 1 mile as described here, so this description cannot be referring directly to them, even by mistake. But when we look at Werlich's map overlay of the UFO track in the Blue Book file (see *Fig.11* below) showing a closure of the echo from 3 miles to 1 mile off the left wing near the VOR beacon fix, it is equally clear that there is no 3000 mph closure here either: Assuming constant echo bearing from the B-52, the closure shown beginning at point *b* in the figure takes place on a track of about 3.5 miles over at least 8 radar scans (24 seconds or more), a ground speed of only about 520 knots. So this tells us that Werlich must have been referring to other information, about a different target movement, gleaned presumably from the navigator, Pat McCaslin, during the debriefing.

initial radar events near the turn over the TACAN approach fix

McCaslin's very clear recollection is that the target was first detected by him to the *right* of the aircraft on the outbound leg *before* the aircraft had completed its 30/180 turn back onto the approach heading. This sequence at first sight appears inconsistent with Col. Werlich's 1968 statement in the AFR 80-17 report telex that the echo appeared "after rolling out of [the] right turn". However, as we have seen Werlich's summary statements quoted above are themselves internally inconsistent and bespeak some confusion.

Werlich obviously realised quite soon that the photos which Clark had printed up were not taken (as Clark apparently had always believed they were) at the start of the incident, but rather at the end, and he makes this plain in the file. But it may be that this realisation was responsible, ironically, for the confusion that appears between Oct 24 and Oct 29 in his account of the start of event. He may have edited out his Oct 24 references to 3000 mph, and to the transit from right wing to left wing, because in his mind these features became conflated with the rather similar photo sequence originally, but (he now realised) mistakenly, placed at the beginning of the event. But although it may be correct that there had been confusion, Werlich's Oct 29 revision, rather than clarifying the issue, introduced further confusion.

It wasn't only Werlich. The evidence is consistent with a rather general confusion on this point, both in 1968 and since. As mentioned, it appears to have been present in Richard Clark's mind, and McCaslin's own recollection suggests that he may have conflated the photointerpretation and his own memory of the initial sighting in a very similar way.

McCaslin's account clearly describes fast motions of the echo only near the start, followed by its steady pacing of the B-52 off the left wing until the time it finally disappears. So when he describes (interview with Tom Tulien, Feb 2001) being shown the film sequence in a later debriefing at Minot, it appears that he is mistakenly associating these kinematics with the start of the event:

> . . . it's that that they used to calculate the speed. That's where I found out what the speed was, during that session. They said, 'We figured the speed was…', and I forget. It was a phenomenal amount of…it was a phenomenal speed. And what's important about that is not the speed, but the fact that they could instantaneously go from one speed to the next, and then instantaneously resume the speed that the…the prior speed. That was more impressive to me than the actual speed, although that was impressive enough.

The same conflation occurs explicitly later in this interview. McCaslin had been sent poor copies of the scope photos in late 2000 and is describing how he interpreted them:

> PATRICK: The…the blip I saw would have been when we first picked it up.
> INT: Okay.
> PATRICK: It was on the outbound leg. And…and the scope photos I saw had none of the stuff from inbound. None.
> INT: Oh, okay.
> PATRICK: All that's missing.
> INT: When you say 'inbound', at what…
> PATRICK: After we turned from the te-or after we turned and started our descent.
> INT: Okay, you don't see anything…
> PATRICK: All this stuff…all the stuff that I saw on that package was outbound.
> INT: Okay. From the beginning of the incident?
> PATRICK: Could've been slightly prior.
> INT: Oh, okay. Okay.
> PATRICK: But there…there was…it was hard to tell because of the quality. I could tell from the heading that we were outbound. I could tell…I saw one blip, maybe two that were what I think is the…the return, and it was in the right position and all that stuff. Three miles out, off the right wing.

In fact, we now know that McCaslin was here misreading the photos. There are certainly none from the outbound leg at all. This is an understandable error because these were extremely poor prints made from microfilm copies of the Blue Book file; the investigators had not at this stage discovered the good quality set retained by Richard Clark.

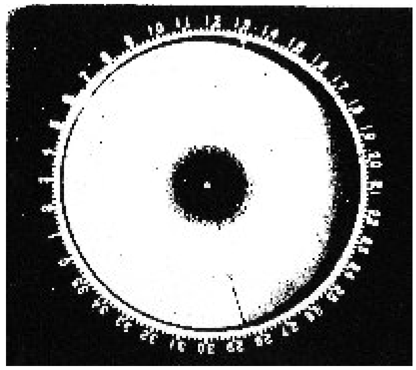


Fig.10 Image from Blue Book microfilm of frame #776

Just visible on this otherwise useless copy is the radial line at ~285 degrees caused by a 50 msec capping of the shutter to allow film advance.

The hypothesis is this: The radial feature that McCaslin is reading as the heading marker on the radar scope is actually a photographic artefact (*Fig.10*). A thin line runs across the ground echo towards about 285 degrees due to the shutter closing briefly at the point of film advance between each 3-second scan (see discussion below). Because of the atrocious print quality the real heading marker was completely invisible. Bearing in mind that McCaslin had last looked at such an ASB-9 radar scope decades earlier, we can see how the illusion was naturally encouraged because the phony "heading marker" happens to lie close to the outbound heading on which he knew the B-52 was flying at the time the echo first appeared:

INT: . . . . Those are probably the best copies we've got, right there.
PATRICK: Okay, see, you can't tell…it looks like…I can't even tell the…hard to tell the time, even.
INT: Yeah, I know. They're hard to read.
PATRICK: Uh, but you can see…we're outbound. There's the heading indicator right there, the track.
INT: Okay, that's the direction you're going…
PATRICK: And we're headed northwest.
INT: Are these the TACAN numbers?
PATRICK: No, those are the…that's the…
INT: Degrees?
PATRICK: …the heading. Yeah. So we were headed.
INT: No, not even degrees, are they?
PATRICK: Yeah, they're degrees. This is 280.
INT: Oh, okay. I'm sorry. Okay.
PATRICK: So you're headed northwest, right here. [. . .]
INT: 285.
PATRICK: 285, yeah. We're outbound.
INT: Almost 290 [inaudible].
PATRICK: That could not be the inbound…
INT: Okay.
PATRICK: …return. So this was…this was on the way out.

McCaslin's testimony appears unequivocal on the point that the radar event began before the turn with a strong echo 3 miles off the right wing. Indeed, when we look at Werlich's own map overlay in the file (see *Fig.11*), plotting both the B-52 flight track and that of the unknown, we find that he indicates, in addition to the UFO track pacing the inbound plane off the left wing, another static location about 3 miles off the plane's *right* wing on the *inside* of the outbound turn. This location off the right wing of the plane *before* the turn, and the location of the first appearance of the echo off the left wing *after* the turn, are both marked with the same red cross and are both connected to the B-52 flight track by what appear to be identical dashed lines evidently indicating lines of sight between synchronous positions.

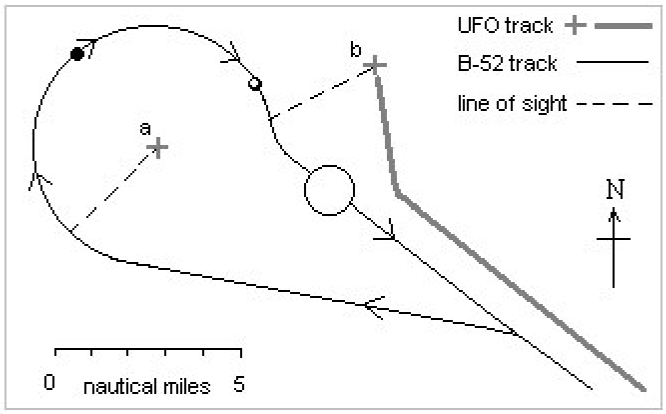


Fig.11 Diagram of B-52 and UFO tracks during the turn

The large open circle is believed to represent the VOR beacon fix for the approach path to Minot AFB runway. The small black circle represents approximately the B-52 position at which the ASB-9 radar echo could have begun to cross the flight path from location a towards location b, maintaining about 3 miles separation as described by McCaslin. The small open circle represents approximately the B-52 position at which the echo could have crossed from a to b in the space of 2½ radar scans (7.5 seconds) at an average rate of about 3000 knots (see text). (Approximately to scale. Adapted from Col.Werlich's map overlay)

McCaslin's first uncontaminated memory, as given to Jim Klotz in an interview in Nov 2000 without sight of other historical documents or witness statements, is worth quoting here:

> as we were climbing out and approaching the VOR, I remember I noticed off to the right on the radar a faint return about three miles out, and uh… which would have made it to the north... and ah…
>
> JK OK, And you were headed west.
>
> PM We were headed west-northwest, I think, and then about uh…and then in the next sweep of the radar, it was a very bright return, and it was a *big* return, it was at least as big, maybe bigger than the return a KC-135 would make, which I'd seen many times.
>
> JK Wow.
>
> PM So I alert the pilots to that. I said 'here's an aircraft or something off the right wing three miles.' Well, they could see nothing and they told me to keep them advised of it. As we approached the VOR, they were going to have to turn right *toward* this thing, so I told them, you know, 'I'll just keep an eye on it.' And they turned right toward it and uh…and as it… as we turned right toward the VOR it moved off to the north and *maintained* that three mile separation, so as we rolled out, it was at three miles off our left wing, and we were headed back toward the base now, uh starting the approach. I alerted the pilots to *that*, and they still couldn't see anything visually.

So this phase of the event appears to be corroborated directly by Werlich's 1968 map overlay and indirectly by Werlich's initial citation (Oct 24 memo) of details which we cannot trace to any other origin than McCaslin's testimony given in debriefing that day: "Initially the target traveled approximately 2½ mile in 3 sec or at about 3,000 mi/hr. After passing from the right to the left of the plane it assumed a position off the left wing of the B-52."

The *simplest* reading of this is that the *transit* from right to left of the aircraft was the initial 3000 mph motion. Is this feasible? Neither McCaslin nor Werlich describe this transit in detail so the significance of "2½ miles" is uncertain. But evidently 3 seconds is the crucial figure here, since this is the scan period of the radar, suggesting that 2.5 miles is just a calculated scan-to-scan displacement and does not have any other particular kinematic significance. Evidently the geometry of *Fig.11* tells us that a rapid target motion between Werlich's two "+" positions must, roughly speaking, entail some odd multiple of a half rotation of the radar if seen from some point coming around the top of the turn towards the TACAN fix, so 1½, 2½, 3½ etc. In fact if we measure the distance between these positions in *Fig.11* we get about 6.3 miles, which at the cited rate of 0.83 miles/sec corresponds to a little more than 2½ rotations of the radar screen beginning at about the point marked by a small open circle in *Fig.11*. This could conceivably be the origin of the vexed "about 3000 mph".

Alternatively McCaslin's own later description of this echo transit, as "maintaining a 3 mile distance", could be taken literally, in which case a much slower echo motion would have begun with the B-52 somewhere near the small black circle in *Fig.11*. Then the origin of Werlich's "about 3000 mph" is back in contention. We could try to connect it with McCaslin's recollection that just after the transit the echo closed suddenly:

> We started the approach, and uh, again it was out there at three miles off the left wing. At some point, I don't remember what altitude, the pilots were descending toward the base, but at some point this thing, uh, from one sweep to the next it moved from three miles off our left wing to one mile off our left wing.

But even a displacement of 2 miles relative to the B-52 in 3 seconds is equal to a speed of only 2400 mph, not 3000 (correction for ground speed is negligible). There is also no indication of this specific movement on Col. Werlich's track overlay, nor any other unambiguous contemporary record of such a movement. So this issue cannot be definitely resolved.

the radar film sequence

Howsoever, returning to the radar film sequence, the result of the present analysis suggests that Richard Clark was correct that the 13 photos which he ordered printed up were the start of the photo sequence, but that there has been some confusion, both in 1968 and since, between the start of the *event* (correctly recalled by McCaslin and ambiguously recorded by Col. Werlich) and the start of the *photography*.

Further evidence of this emerges when we try to explain why the first of the numbered frames, #771, appears to capture a half-revolution of the radar sweep, hitherto assumed to mark a change in the scan mode at the start of the event when the radar was first put into

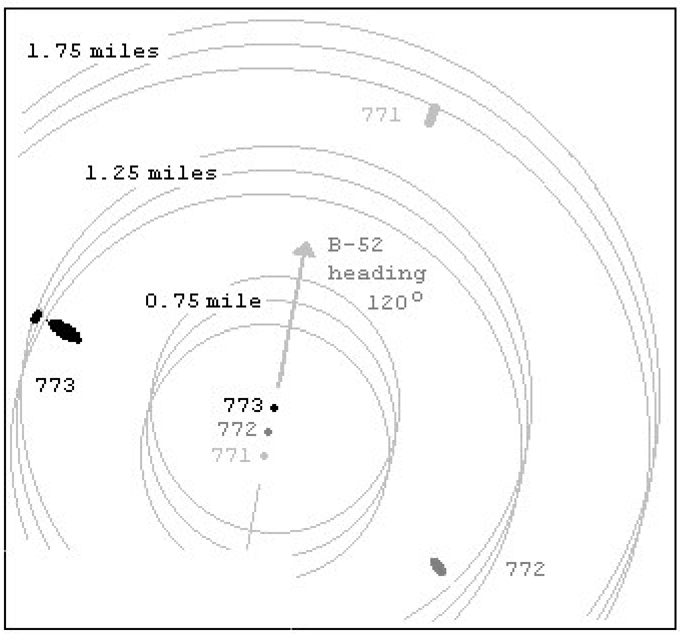
Station Keep (see *Section 2* above). Training Manual CDC 3210K Vol.4 discloses that the operation of the camera, rather than being a snapshot of the PPI display capturing an image with a persistence comparable to the 3 second rotation time, is a time exposure, the shutter being open for virtually the whole 3 seconds. (I initially assumed that it was snapshot because the moving clock second hand and the number counter are "stopped" by a brief exposure. But the brevity is explained by the fact that the clock and counter are physically separate from the PPI and photographed through a different lens system. The images are combined by a double exposure.) The PPI exposure is controlled electrically by a loop from the antenna rotation mechanism. At a certain point the rotation closes a circuit and sends a voltage to the camera shutter and film advance mechanism, capping the shutter for 50 milliseconds during which time a motor winds the film to the next frame.

This momentary interruption appears to be marked by the narrow dark wedge visible on the photos between 280 and 290 degrees (strictly, capping the shutter for 50 milliseconds ought to interrupt the image over an arc of 6 degs; the wedge visible is always much less than this angle for uncertain reasons). This is the radial line suggested above as the origin of McCaslin' s mistaken "WNW heading marker" on a negative print. Frame 771 therefore shows the shutter opening with the PPI sweep at about 100 degrees followed by a time-exposure of approximately 1.5 seconds until a voltage from the antenna rotation mechanism trips the camera shutter, closing it at 284 degrees and causing a fresh frame, # 772, to be advanced into place. In other words #771 shows the instant, nearer the end of the event than the beginning, at which the *camera switch* was operated, rather than the instant at which the radar' s Station Keep switch was operated.

The only evidence which on the face of it might contradict this scenario is Richard Clark' s recollection that there were originally a great many more frames than the 13 he had printed, possibly over a hundred. A hundred frames would represent a further 5 minutes of photography, but the aircraft altitude is persuasive evidence that the photos we have were taken shortly before the echo disappeared, as stated by Col. Werlich in 1968, and Werlich' s contemporary track chart shows a "radar film area" approximately 2.56 NM in length, consistent with 13 photo intervals of 3 seconds at the B-52 speed, not more than 13. A further 5 minutes of UFO photos *after* #783 seems impossible.

On the other hand, this is only evidence that there were no further frames showing anything of interest; it is not evidence that were no other frames. The B-52 did not land immediately, but executed a missed approach and went around at low level in order to overfly the reported "landing" location before finally putting down at Minot AFB. It would be natural practice if the radar was left in operation during this go-around, since one doesn' t know that the target has gone for good, and indeed the aircrew testimony is that they were instructed by radio to film the ground during this overflight. Since the B-52 carried no operable camera other than the radarscope camera this can only mean that the radar remained operational and that the camera was running. Probably it was left running until touch-down or until the film ran off the spool so that the complete roll would have been taken from the aircraft after landing by the intelligence analysts.

This would be consistent both with Richard Clark' s recollection that the camera was switched on belatedly (as concluded here) and left running until they landed, producing a great many frames, and with the fact that he said "I had them print every significant image", recalling "nothing of any value" on the later frames (see also *Note 4*). On the succeeding frames the altitude hole radius would dwindle rapidly, even with the antenna tilt at maximum elevation in Station Keep, and would vanish entirely long before the aircraft descended to a couple of hundred feet to execute its low approach over the Minot runway. After this the B-52 never recovered sufficient height for the altitude hole to reappear. They overflew the "landing" location at a reported 1500 ft, which is comparable to the minimum range of the display (the ~2000ft TR-hole radius caused by de-ionisation delay in the antenna duplexer). So these frames would not be able to show any targets in the air, only a scope completely saturated with ground return. It' s very probable that the echo from any object on or near the ground would have been lost against the ground echo itself. But even if this ground-scan did contain latent information of use to someone who knew what they were looking for, Richard Clark did not not know about any UFO on the ground and was not himself asked to look for evidence of it.



Frames 771, 772 & 773 superimposed to indicate displacement of the frame of reference of the radar at 3-second intervals at the mean ~250 mph speed of the B-52. (This is a simplification of the true renewal rate; see below)

Only approximately to scale.
(Note that the range scale is slightly non-linear and changes between the first and subsequent rings.)

Fig 12. Diagram of relationship of PPI echoes in Phase A

With all this in mind we can refer to the situation illustrated in *Fig.12* in order to begin to derive limits for the approximate true (average) target speeds that would be implied by the echo displacements in *Phase A*.

the filmed echo speeds

Note first that if we use a constant 3 second update rate to calculate echo displacements relative to the B-52 and then correct for the ~1100 ft movement of the B-52 (average estimated groundspeed) per photo interval, we find maximum target groundspeeds in both cases (assuming co-altitude) in the region of 2000 mph. This appears inconsistent both with Werlich' s "3000 mph" and with Richard Clark' s recollection that the Bomb Wing intelligence photoanalysis in 1968 (presumably employing a similar correction with access to accurate air speed data) calculated a figure of approximately 3900 mph (presumably nautical miles per hour).

However things are more complicated because although the scan rate and the photo update interval are synchronised at approximately 3 seconds, the echo renewal rate also depends on the motion of the target. The renewal rate of a relatively stationary target or a target on a constant bearing will also be 3 seconds; that of a target with an azimuth rate will not, and the correction depends on the rate and on whether it is positive or negative in relation to the antenna rotation direction.

The trace rotation direction on the ASB-9 being clockwise it is easy to see that the total time interval corresponding to 460 degrees of rotation between the echoes captured on frames 771 and 772 is roughly (460/360) x 3 seconds, or 3.8 seconds, and the displacement (roughly 2.1 NM in 3.8 seconds relative to the B-52, assuming co-altitude) indicates a *maximum* velocity of ~ **1990 knots** relative to the B-52. On the other hand whilst the blip on frame 772 follows that on 771 by *more* than one 360 degree rotation period, the blip on 773 follows that on 772 by *less* than one rotation. It must be painted when the trace has rotated only about 115 degrees after the triggering of the frame advance at the end of exposure 772 in order to appear on the screen at the time of frame 773. The trace has rotated about 160 degrees between the two paints. So, the displacement between frames 772 and 773 (approximately 2.1 miles in 1.3 second) indicates a co-altitude maximum of ~**5870 knots** relative to the B-52.

Neither of these speeds corresponds to anything in the original air force file. However, we should also consider that it is impossible to determine acceleration without a minimum of three points of measurement on any trajectory, so that each of these speeds is in fact only an average. When we take the overall average of these two speeds (which is equivalent to taking the average rate of a single accelerated target measured at three points, 771, 772 and 773) we get a co-altitude upper limit of almost exactly **3900 knots**, suggesting that this is very likely the route by which a speed of "3900 mph" was arrived at by the Bomb Wing photoanalysts in 1968 as recalled by Richard Clark.

Of course this a measure of displacement relative to the B-52. Applying small corrections for the approximate speed and heading of the aircraft then gives us true (average) ground speeds. This correction has the effect of somewhat reducing the true average rate of the first displacement and very slightly increasing that of the second, giving maximum co-altitude values of about **1873 knots** (771-772) and about **5877 knots** (772-773) with an overall average of **3875 knots** (~ 4450 statute mph).

The reader will have noticed that the above displacements are measured assuming the default case of co-altitudinal targets (zero degrees relative elevation) and so are *upper limiting values*. I am grateful to Claude Poher for pointing out the importance of the unknown elevation angle(s) of the target(s). Because of the depression angle of the radar cover the physical distance between two target positions within the beam can be very much less than would be indicated by their slant ranges as projected on the PPI display. In other words this is a problem in spherical, not plane, trigonometry.

frame interval	maximum	minima for two values of θ	
	$\theta = 0^o$	$\theta = -50^o$	$\theta = -60^o$
771 - 772	1873	1246	935
772 - 773	5877	3607	2844

Table 3. Average implied groundspeeds

Showing dependency on depression angle. Maximum values occur if the target is co-altitudinal with the B-52 ($\theta = 0^o$)
Speeds are in knots

Some limiting solutions, assuming horizontal trajectories, are summarised in *Table 3*. The -50 degree value represents the specification figures used in this analysis. Note that maximum speeds consistent with Claude Poher' s reconstruction of the B-52 flight track, and a -45 degree coverage limit, would be slightly lower still. (The values for -60 degrees represent the coverage diagram in *Fig.3*, although there is no good evidence that this diagram is other than schematic.) We can see that the range of possible implied groundspeeds is considerable.

6. Interpreting the Unidentified Echoes

In *Section 5.iii* it was found convenient to divide the photo sequence into two phases - *Phase A* (frames 771-773), the ostensible rapid motion of the blip from off the right nose of the B-52 to a point behind the right wing before crossing to a point off the left wing; *Phase B*, (776-782), the reappearance of the blip stationed persistently off the left wing. We follow the same convention. The method here is eliminative, an attempt to determine beyond reasonable doubt what the "echoes" are *not*. Some reflections and conjectures will be offered in *Section 7*.

a) meteors

Whilst the persistent *Phase B* echo has no similarity at all to a meteor return, echoes such as those to the right of the aircraft in *Phase A* could conceivably be due to a meteor or meteors.

Meteors generate a high temperature plasma due to ram heating of the air, which can be detected on certain radars. Generally it is the long trail or wake ionisation which is detected, acting as an efficient re-radiator when favourably oriented in relation to the radar. The trail will be scanned as an effective point target on a single sweep because the recombination time of the plasma is very short and the typical flight time is less than the rotation period of most surveillance radars.

In the present case the successive echoes are far apart (~100 degrees of azimuth) and a relatively fast 20 rpm rotation rate means that a single unusually long-lived meteor detected on one scan (frame 771) *might* still have been within the coverage pattern when the antenna rotated back towards it approximately 3.8 seconds later (frame 772). We can show (see *Section 7*) that the detail of the echo presentation is not inconsistent with two consecutive echoes from a single fast-moving target passing through the drum, provided that the effective target echoing area for 3cm radar is in the order of several hundred feet long on a major axis alligned with the direction of motion. However unlikely, in principle this could be two returns from the head echo of a very large fireball.

Taken at face value the echo displacement would indicate a maximum speed of 1870 kts (~ 2160 mph), which is between one and two orders of magnitude too low for an ordinary shower meteor and requires a flat trajectory at zero degrees relative elevation. The radar coverage pattern, having a top-edge elevation of only about 8 degrees (a maximum, remember, since the characteristic target for this pattern is a large jet aircraft; see *Section 5.ii*), also implies this: An elevation 8 degrees above flight level requires a detectable1st-trip target at 1.62 miles real range to be at about 11,000 ft or less - i.e., a spectacular slow fireball roughly co-altitudinal with the B-52.

Such a fireball implies an abnormally slow meteoroid that has been further dramatically slowed by tropospheric braking and has a very good chance of surviving to the ground. Could a fire caused by an impacting meteorite, or fragments from an air-detonating meteorite, explain the "landing" and the bright glow observed later at ground level from the B-52? Leaving aside for the moment the fact that this wouldn' t help to explain the immediately consecutive *Phase B* radar echo, several arguments make this theory very unlikely.

The position of the B-52 when the echo finally disappeared is given in the original reports as 296 degrees radial 14 NM from the Deering TACAN beacon adjacent to Minot AFB runway. The "landing" location to which the B-52 returned and where it overflew the ground light is also given with fair accuracy. Col. Werlich gives this position as "320 radius,16 NM" from the TACAN beacon, corroborated by ground-visual reports. These locations are some 7 miles apart. The relative position of echo 772 is also known accurately - about 3 miles at 300 degrees from the final *Phase B* echo position on frame 782 and therefore some 10 miles from the "landing" location. So a meteor on a shallow trajectory (see below) travelling almost 1 mile/second on a heading of about 338 degrees magnetic would have to arrive at an impact point some distance even further away to the NW than this, leading (conservatively) to a *minimum* distance of maybe 15 miles from the nearest likely impact point to the nearest possible ground-visual position. Given that the B-52 approached to within a mile or two of the location of the ground light at only about 1500 ft this discrepancy seems far too large to reconcile. (If Claude Poher' s calculation of the B-52 position at frame 783 is accurate, then the discrepancy between the two locations is even increased by several miles.)

No sign of impact or fire damage was discovered from later helicopter survey of the site, or anything else to explain the structured object seen from the B-52. There is no evidence of reports from farmers or claims of damage, and nothing was recovered. A search of various on-line meteor resources produces no record of a meteorite fall on this date in N. Dakota. Moreover there was no visual report from the B-52 flightdeck of a spectacular fireball streaking past the right wing below the clouds, nor do any of the many ground observers who were watching the skies at that time describe a possible fireball.

So a close-range fireball seems to be ruled out. If we forget the "landing" these problems might be evaded by invoking a reduction of displayed speed due to multiple-trip returns from a remote meteor passing beyond the unambiguous range of the radar. At 2nd-trip distances of ~70 miles slant range the angular rate corresponds to a more reasonable velocity of about 170,000 mph (3rd-trip would double this rate). On the other hand a remote meteor would make a proportionately very poor target (signal attenuation going as the inverse 4th power of the range) becoming problematic in terms of the 3cm wavelength of the ASB-9, which is already two orders of magnitude shorter than optimum for returns from meteor ionisation. Moreover the implied trajectory for first-trip passage through the shallow drum of the radiation pattern is a shallow path only about 20 degrees off a reciprocal heading, therefore a large angle away from the favourable "radiant condition" which occurs with meteor trails orientated normal to the radar line-of-sight.

So once again this implies strong head echoes from a very large fireball-type meteor, rather than the more usual echo from a favourably oriented particle trail, and now the requirement for a large radar cross-section is even more stringent. An angular displacement of 100 degrees between paints implies a meteor detectable over a track length of around 200 miles for several seconds, picked up at 2nd-trip range and on an inefficient wavelength.

Simple geometry shows that a 2nd-trip track detected twice on successive scans at about 70 miles passes within a slant range of about 45 miles from the radar (whilst the antenna is "blind" and rotating through the reciprocal sector). Even though 2nd-trip on radar, this is still a "nearby" visual meteor in the local sky since the vast majority of meteors burn out at altitudes well above 50 miles, and it should have been a prominent visual object low in the SW sky (low elevation angle implied by radiation pattern) streaking westwards at ~ 35 deg/sec for several seconds.

It seems possible that the reported presence of haze (the aircraft was probably flying within or close to haze and/or patchy overcast at the time of the photographs) and a second layer of broken overcast at about 25,000 ft (about 3 miles above the flight level) could have prevented visual observation. However, ground observers apparently were in a position to see Sirius and/or other astronomical bodies in the southern sky according to the Blue Book hypothesis, so the degree of likely obscuration is arguable. Most observers reported seeing some stars. Even with broken cloud cover one might expect that so colossal a bolide would be seen by at least one of the many people watching the southern skies from around Minot, and if not by them then by somebody somewhere in N. Dakota. The incident took place within the time frame of the annual Orionid meteor shower, about 15-25 Oct., and meteor showers are routinely observed by professional and amateur astronomers, but no reports are findable of a remarkable fireball seen during the Orionid shower of 1968.

Taking a different tack, note that we cannot necessarily infer continuity from two or three widely separated paints. It is also possible that two *different* meteors could be detected on successive scans. From the region of Minot ND the Orionid radiant (RA 92 degs; Dec.15 degs N) culminated at about 50 degrees elevation due south at about 0400 local time on the morning of Oct 24 1968. The typical Orionid rate at maximum is about 20 meteors per hour.

Suppose that successive Orionids pass within only a few miles of the airborne radar and so are detected as first-trip targets. Detection might then occur even at the unfavourable 3cm wavelength of the ASB-9, because although the returned power varies as the cube of the wavelength it varies as the 4th power of the range, and the gain due to very close proximity could outweigh the loss due to short wavelength. Travelling at perhaps 50 miles per second a meteor could pass through a 2-degree radar beam (a few hundred feet wide at the indicated first-trip ranges) in a few milliseconds and a wake echo could be scanned as a short streak at almost any azimuth.

But again, 1st-trip echoes from meteors only a few miles from the radar would still imply large meteors that survived ablation down to below about 12,000 ft. Such meteors would definitely be bright visual fireballs, and now we have two, in startling proximity, instead of one only moderately close by. Second-trip ranges would allow ordinary shower meteors at altitude; but two ordinary Orionids at 2nd-trip ranges are not likely to have been detected on this X-band radar in the first place, so again we are back two fireballs instead of one. This is not an attractive alternative.

In summary the least unlikely meteor scenario to explain echoes 771 and 772 would be second-trip echoes from a single very large fireball, passing within about 45 miles south of the radar on a heading of approximately 290 degrees true.

There is no visual evidence consistent with a fireball, despite large numbers of ground and air observers sensitized to "see UFOs", but this is not conclusive owing to the presence of broken layers of cloud and haze above 10,000 ft. On the other hand, these clouds were apparently not dense enough to prevent observation from the air and/or from the ground of the stars Sirius and/or Vega (according to the Blue Book hypothesis).

A large fireball is *a priori* an improbable event, and a complicated relationship between speed, mass and the altitude of ablation means that fireballs in the N hemisphere have a maximum frequency in Spring and in the evening. In North Dakota, an early morning hour, in the Autumn, is exactly the least likely time to observe a fireball.

There is no connection to the culminating Orionid radiant, which is at this time 30 degrees of azimuth south of the southernmost possible origin of the implied radar track, so we have a pure coincidence with the Orionid shower.

Fireballs are observable over a wide area. I can find no other reports of possible fireballs for the date and area, either in UFO report lists or in meteor observation records. Admittedly the local time would not conduce to large numbers of potential observers;

nevertheless the absence of other reports adds to the cumulative improbability of a fireball explanation already coincident with unrelated local visuals and a Minot AFB weather-radar target.

Finally, given the coincidence of an immediately consecutive persistent ASB-9 radar echo (*Phase B*) which can have nothing to do with meteors, the meteor hypothesis for 771 & 772 should be rejected as highly unlikely.

b) aircraft & missiles

In this case the explanation is conceivable (in principle) for *Phase B* but is rather more difficult to apply to *Phase A*. The implied speed of about 2000 mph between frames 771 & 772 appears to rule out successive paints from one conventional aircraft. There were a few aircraft flying in late 1968 capable of Mach 3 (e.g. the SR-71 or the new Soviet Mig-25), but only at high altitudes many times the radar-implied altitude of under about 10,000 ft. (Invoking multiple-trip echoes is no help in this case as displayed rates will always be slower than true rates.)

This leaves the possibility of different aircraft passing sequentially through the radar cover, each being painted for only one scan. The shortest distance through the complete cover at the displayed ranges would be steeply up or down, normal to the boresight angle. If we say that the vertical cover is nominally 60 degrees (the actual profile is of course a complicated function of range and elevation defineable only in terms of a probability of detection for a given radar cross-section) and the renewal rate is nominally 3 seconds, then we have the very approximate limit values shown in *Table 4* below.

#	range (mi)	min. length of track (ft)	implied speed (mph)
771	1.62	7,400	1,682
772	1.05	4,800	1,090
773	1.05	4.800	1,090

Table 4

These speeds are certainly lower than the ~2000 mph rate we are trying to explain away, but this result is not very helpful inasmuch as no aircraft could possibly exhibit such rates of near-vertical ascent, or descent, at heights under 10,000ft - certainly not survivably (*Note 9*).

Actually because of the near-saturated ground echo filling the scope beyond about 2.1 NM it would not be necessary for an aircraft to pass in and out of the entire radar cover (slant range 5 NM) during one scan. The shortest path in and out of the ground echo would in each case be the chord passing through the echo position at right angles to the radius. For 771 this path is 2.45 NM long, and for 772 it is 3.66 NM long, allowing aircraft to be painted only once whilst passing through in either direction, re-entering ground echo after total sweep rotation angles of 395 degrees and 420 degrees respectively, at about 1633 mph (1420 knots) and about 2128 mph (1850 knots) respectively. But this is a highly artificial hypothesis since it requires each aircraft to be painted at the middle of its track and each track to be at right angles to the line of sight, so these rates are improbable minima, and even so they are still excessive - target 782, particularly, is now even more of a problem than it was before.

On the other hand if the tracks are radial then an aircraft could travel directly outwards from echo position #771 into the surrounding ground echo on the shortest path of about 0.35 NM in 3 secs at a speed of only about 480 mph (450 knots), and another aircraft could travel 1.05 NM outward from #772 into the ground echo in 3 secs at about 1450 mph (1260 knots). These figures look better, but they are not really. An aircraft presumably has crossed the scope diametrically to reach the start points of these radial tracks in the first place, and therefore should have appeared in the opposite sector of the same scan 1.5 seconds before. This is not an issue for 771 inasmuch as the photo exposure does not record this scope sector; but once again for 772 this only exacerbates our problem, leading to a minimum average speed (assuming level flight) of about 2900 mph (2520 knots).

We can suppose any arbitrary kinds of circuitous climbs and dives to try and evade these issues, but the result becomes more contrived and improbable. In general, two aircraft must have come from and gone to somewhere, and this activity was taking place close to the terminal manoeuvring area of a SAC air base with a B-52 positioning itself for final approach, limiting the plausibility of the idea that aircraft might have performing manoeuvers at high speed in the vicinity.

According to the AFR 80-17 report telex to Blue Book:

> j. Location, approximate altitude, and general direction of flight of any air traffic or balloon releases in the area that might account for the sighting.
>
> NO OTHER AIR TRAFFIC OR BALLOONS WERE IN THE AREA

All of the ASB-9 echo positions indicate altitudes no more than a few thousand feet above or below the B-52 which, even if marginal for the ASB-9 coverage, should have been well inside the coverage of any airfield surveillance radar. An unidentified aircraft flying below the B-52 could be unresolvable on the PPI of a ground radar from the echo of the B-52 itself, but the aircraft has to get there in the first place. Excepting the ambiguous evidence (in the RAPCON transcript) of a contact with one unknown target near the B-52 on the Minot weather radar for an unknown duration prior to the airborne radar contact, there is no evidence in the file indicating the presence of any aircraft that Col. Werlich, SAC or Blue Book are inclined to acknowledge.

Notwithstanding that there was "no other [known] air traffic", the lighted object seen either close to or on the ground from the flight deck suggests that the object could have descended below any radar cover, and even landed, consistent with what the official report describes as "a simultaneous ground sighting [of an apparent landing] in approximately the same location." But this could obviously not have been a fixed-wing aircraft unless it crashed, and according to Col. Werlich daylight reconnaissance from the air revealed nothing in the area. Covert recovery seems highly implausible. So this leaves the remote possibility of an incursion by an unidentified helicopter.

According to ground observer SSgt. James Bond at N-1 "the object acted like a helicopter". But during the air radar episode the *minimum* altitude of a helicopter in the radar cover would have been (slant range about 5000 ft and assuming a maximum depression angle of -52 degrees) about 4000 ft below the B-52, or a similar altitude above the ground. For long periods during arrival, pacing and descent a helicopter should have been inside the ground surveillance cover, and helicopters with their bulky geometry and the large swept-area of lift and tail rotors tend to be very prominent targets. Also, 250 mph is extremely fast, and although several ground observers clearly heard jet noise from the B-52 at some thousands of feet, there were no reports of rotor noise from a low-level helicopter.

In short, known fixed wing or rotor aircraft seem very implausible.

There remain the remote possibilities of *a*) one or more experimental stealth vehicles with radar aspect ratios designed to minimise ventral ground radar cross-section but still detectable side-on or in dorsal plan from the relative altitude of the B-52, or *b*) deliberate spoofing using small unmanned jet drones with vanishing radar cross-sections, augmented by onboard active jamming against the B-52 radar to explain why the ASB-9 *Phase B* echo was said to be "larger than a KC-135 tanker" or comparable to another B-52. It might be consistent with this that unusual responses were also claimed to have been detected on ECM gear in the plane (although this is a second-hand report uncorroborated by the plane' s EW officer) at the same time as its two UHF transmitters were blocked (see also *Section 6. f* below).

The state of the art in secret experimental stealth techniques in 1968 is not known to this author. Presumably an early full-scale concept demonstrator of a stealth design is a possibility. Remote regions of N. Dakota were apparently used for test flying and special tactical training, and what is known as an "oil burner" run for high-speed low-level flights was reportedly maintained in the Montana border area west of Alexander, where SR-71 trials were conducted. This run is over 100 miles W of the sighting location however. Ground observers near Minot generally reported bright lights, or a "wiener-shaped" object; but in one case an observer looking directly overhead described an object looking "similar in outline to a stingray fish" accompanied by jet sounds steadier and lower-pitched than a normal engine. This is intriguing; but cruising "real slow when overhead" at low altitude and generally behaving "like a helicopter" does not suggest any known fixed-wing jet. Would any experimental stealth vehicle be flying around over an ICBM missile farm, brightly lit, in full view of many potential observers? No protoype VTOL version of the stealth fighter is known to have been developed, and presumably the crash of such a vehicle would spark a major incident.

Perhaps a small RPV is more likely. Many and varied military RPV programmes did exist in the US during the late 60s, Army, Navy, Air Force and private venture, and some of them have exotic-looking shapes. Teledyne Ryan, for example, had been building a prolific series of pilotless jet targets and ELINT platforms since 1951, and some carried multiple jammers as well as other ECM devices. The B-52 itself was designed to carry several small pilotless ECM decoys. From about 1960 until the late '70s the decoy used was the ADM-20 Quail, which could fly for 30 minutes at up to 500 mph whilst using onboard ECM equipment to simulate the radar signature of a B-52.

If one or more experimental RPVs had been deployed during a covert test of the B-52's EW systems they might have used directional active jamming tailored to the ASB-9, and possibly basic stealth techniques such as non-metallic construction and radar-absorbent paints to aid in suppressing their already-small ground radar skin-paints. (This brings to mind the apparently mobile small "negative echoes" in the ground return behind the B-52, discussed as features #2 and #3 in *Section 5.i* above. Stealthed targets might show up as holes in the ground return. But there is evidence that #3, at least, must be a system artifact.) Such a small and/or stealthy object could be a marginal target for ground radars whilst generating a very large false 'echo' on the airborne radar. If an experimental RPV had failed and crashed near Minot it could account for the bright orange glow on the ground seen later from the flight deck.

But this is a rather desperate speculation. After a 10-hour flight the B-52 crew were preparing to make a final approach for landing, systems winding down, ECM gear not operational (according to both the contemporaneous Air Force report and the EW Officer, who remarked that he was probably taking a routine nap at this stage of the flight!) and the pilot evaluation flight virtually over. This is an odd moment to choose to begin such a potentially risky deception, and an odd location, too, in the midst of the Minuteman missile field. And as mentioned, Col. Werlich searched the reported landing area from a helicopter finding only empty farmland, "nothing there that would produce this type of light". How, when, why, and by whom, would an RPV have been recovered in secrecy from the area under the noses of numerous Minuteman security and maintenance teams and SAC investigators?

c) precipitation

The short 3cm wavelength of the ASB-9 radar makes it more likely than typical S-band surveillance radars to detect a sufficient density of small precipitation particles. Thick haze and broken cloud is reported above about 10,000 ft and there are indications of increasing noise speckling on the PPI which could be caused by weather. But such weather cannot explain extremely anisotropic and compact echoes of the strength observed.

It is true that hail showers especially have been observed on radar to form in quite discrete short-lived cells of an order of size not much above the likely first-trip resolution cell in this instance (the resolution cell for a 1.6-degree wide 0.25 microsecond pulse at a range of 2 miles would be about 300 feet in azimuth by 123 feet in range). However a hail cell would not normally form in such extreme isolation, and as mentioned the USAF weather report states that there was no precipitation in the area, let alone the thunderstorm updrafts with which hail showers are generally associated.

Multiple-trip returns from an intense storm beyond the 67.5-mile first-trip unambiguous range of the radar, in the vicinity of the Turtle Mountains massif, could conceivably explain the persistent *Phase B* target off the left wing, since the angular displacement of a point 70 miles away due to the ~2.5-mile travel of the B-52 during the photo sequence is very small (see also *Section 6.k* below). The vertical recirculation of hail cells lofts the particles to altitudes of many thousands of feet (up to 60,000 ft in some cases) and the large vertical extent of echo is characteristic of precipitation. A large storm with hail might conceivably produce a broad echo (the angular width of the #773 echo corresponds to a breadth approaching about 8 miles at the second-trip range) with also a noticeable extent on the range axis due to the vertical height of the storm, which could be as great as 10 miles. The range differential between the top and the base of such a storm from the B-52 altitude of about 1.5 miles would be in the region of 500 feet, which is several times the range resolution of a 0.25 microsecond pulse (123 ft) and might be detectable in principle, but only barely in practice, corresponding to less than 1% of the scope radius (only about 3 mm on the scale of the scope images measured in *Section 5.i*) when typically about 200 spot diameters might be resolvable along the PPI radius. The radial extent of the #773 echo is approximately 4 or 5 times as large, so much too great to be accounted for by the vertical development of any possible terrestrial storm at 2nd-trip range or greater.

Smearing of echoes on the range axis by ghosting, caused by radiation returned to the antenna by two ray paths of different lengths in (hypothetical) unusual propagation conditions, could account for this degree of radial ellipticity and/or apparent doubling of the persistent *Phase B* echo. But it seems likely that echoes received in this way, from multiple-trip distances and also *via* lossy scattering pathways, would require a rather efficient reflector. Therefore types of targets other than weather (for which there is no evidence) might be better candidates for ghost reflections (see *Section 6.j* below).

d) echoes from the moon

At first sight this might seem an extraordinary notion for a 250 kW peak power airborne radar, delivering a mean power of a little over 100W in Station Keep mode (0.25 microsec. pulse, 1617 pps). Moon echoes were first detected by the US Army Signals Corp's *Project Diana* at Ft. Monmouth in 1946 with a continuous wave signal of 3 kW, but they were often observed on early surveillance pulse radars with peak powers of tens/hundreds of kW so it should be considered.

The 0.5 degree diameter of the moon will behave like a point target in azimuth. Because it is smaller than the azimuth resolution of the radar it will present an echo with an angular width comparable to the width of the main beam, appearing at the azimuth of the moon. But because the radar integrates echoes from the entire lunar hemisphere it is not a point target on the range axis. It is also obviously a multiple-trip target (~3500 times the unambiguous range of a 1617 pps repetition frequency). On the scope, echo may appear at any range which is equal to the residual between the true range to a point on the lunar hemisphere and some exact multiple of the unambiguous range of the set, in addition to which the orbital motion of the moon means that a given point on the lunar surface changes range rapidly. When at low elevation near the horizon the range-rate of the moon will be in the order of 1000 mph. In short the echo can have an arbitrary extension on the range axis, might abruptly change displayed range, but will maintain the same bearing from an aircraft in straight flight.

The *Phase B* echo does appear at essentially the same bearing throughout, and has intermittently a curious elongation or ghosting on the range axis. The Blue Book account describes this echo first appearing off the left wing and closing range abruptly from 3 miles to 1 mile (at 3000 mph according to Col. Werlich); although during the photo sequence the echo tends to approach slowly from 1.05 NM to 0.87 NM. Some qualified similarity to a moon echo can be argued, then, and a bearing of 9 o' clock from the aircraft would be ~30 degrees true, which is within 10 degrees or so of the 19-degree true azimuth of moon at 0400 local time on the 24 Oct 1968.

The long axis of the echo(es) is not in all cases exactly radial, deviating up to about 10 degrees in a clockwise direction. The degree of radial compactness and range consistency of the echo is probably also greater than one might expect. But these are minor issues compared to the fact that running an astronomy PC application for the latitude and longitude of Minot at 0400 CDT on 24 Oct 1968 places the moon at a *negative* elevation of -67 degrees.

This is measured from the surface of the earth, not from altitude, and moreover the 4/3 earth-radius radar horizon is always about 15% further away than the optical horizon, so we need to correct this figure. But even from 20,000 ft the radar horizon is only 200 miles away, and the relative elevation of the moon doesn' t change much in 200 miles. This is equivalent to the change in celestial position due to less than 12 minutes siderial revolution of the earth, or less than 3 degrees. Even allowing for the possibility (unsupported by available radiosonde data) that the horizon might be extended by a strongly superrefractive elevated duct we could still be confident that the moon must have been some tens of degrees below the radar horizon of the ASB-9.

e) echoes from lightning channels, lightning sferics & ball lightning

Echoes from lightning channels can be detected as discrete targets, or sferics due to RF radiation emitted by rapidly accelerated electrons in lightning channels can generate more widespread display products. The phenomenology throughout is completely inappropriate for sferics in this case. Successive lightning channels (duration about 0.5 sec) might show up as stochastic point echoes on successive scans around the scope as in *Phase A* if the radar is located in the middle of a storm. But there was no local thunderstorm activity.

The possibility exists of remote lightning strokes being detected by multiple-trip echoes, as plasma column cross-sections are typically in the region of 60m^2 at centimetre wavelengths. But any echoes will be much weaker at X-band than at longer S-band or L-band wavelengths (generally a factor 10 increase in wavelength allows a 100-fold decrease in the necessary electron density for critical reflection) so the short 3 cm wavelength in this case is not very favourable; moreover the shorter the wavelength the more likely it is that lightning channels will be masked by echoes from the widespread precipitation that always accompanies thunderstorms. The *Phase A* photos show nothing resembling this sort of precipitation echo. So these factors combine to make echoes from remote lightning channels at multiple-trip ranges rather unlikely. (Needless to say the duration of the persistent *Phase B* target rules out lightning channel echoes.)

Blue Book concluded that the most likely explanation for the radar echoes was "a plasma of the ball lightning class". Quintanilla states: "Plasmas can effect electrical equipment and can also be painted on radar" and "Plasmas, such as ball lightning, can occur in clear weather as well as stormy weather." This rather misrepresents the fact that, statistically, ball lightning is very strongly correlated with electrical storms, even though there are some reports in the literature of phenomena nominally classified as ' ball lightning' occurring in clear weather. If such phenomena are physically identical to ball lightning or not is a moot question, inasmuch as explaining the sustained energy density of lightning balls has proved difficult enough for theoreticians even with the power of an active thunderstorm to draw on. In the present case it would be fair to say that the general condition of the weather is not remotely suggestive of ball lightning.

Ignoring the supposed hypersonic approach and transit of the B-52, the behaviour of the *Phase B* echo might redefine our understanding of ball lightning. Ball lightning duration is typically only a few seconds. A target with a radar cross-section comparable to a large jet (~ 10-100^2m) pacing the aircraft at ~250 knots for at least half a minute and probably closer to 6 minutes (contemporaneous witness reports) is unintelligible as ball lightning. Speed, duration and cross-section are all at least one or two orders of magnitude greater than the median reported or inferrable values for ball lightning.

Blue Book also suggested a "possible plasma" as an explanation of the luminous object seen visually from the B-52 on or near the ground some minutes later. Multiple lightning balls are almost never reported. The probability of so rare a phenomenon occurring twice in the same area, in the absence of any sign of atmospheric electrical acitivity, is vanishingly small, and if the suggestion is that the *same* plasma was responsible for both radar and visual observations then this remarkable plasma is a "UFO" in all but name.

The malfunction of the two UHF radio transmitters coincident with the proximity of the radar target is not really addressed at all by Blue Book, although some vague suggestion of possible ball lightning-related electromagnetic effects is offered. One (not wholly successful) theory of ball lightning formation proposes that the plasma is sustained by ducted high-intensity radio-frequency fields (never observed), presumably associated with the large-scale vertical charge separation occurring in electrical storms. Some analogous mechanism might conceivably cause UHF interference. But there is no apparent likelihood of atmospheric-electrical RF emissions in this case. Moreover interference is one thing; complete transmission failure whilst preserving reception on the same wavelength is quite another.

It is true that a plasma will scatter radio waves. The UHF radio wavelengths concerned are around one metre (~300 MHz). Any plasma with an electron density high enough to efficiently scatter X-band radar (*ex hypothesi*) will be much more effective at scattering UHF radio. However the only radio waves scattered will be those that are actually radiated in the direction of the plasma. There is no obvious physical reason for a lightning ball that gives a discrete radar echo at 9 o' clock from the aircraft to affect radio waves transmitted forward to a receiver situated at about 12 o'clock ahead of the aircraft.

One can imagine an associated region of sparse ionisation, with a recombination rate not frequent enough to be detectable by visible light emission, which could, if spread over a large enough volume, still have significant opacity at radio wavelengths. If the B-52 were flying within or above such a region its UHF transmissions could be attenuated by absorption. But it is very doubtful that sudden and complete blocking of the transmission "in the middle of a word" could be caused in this way, and again the preservation of UHF reception on the same wavelength is completely unexplained. Moreover there is no evident natural mechanism for sustaining even a rather weakly ionised large volume of air in the absence of electrical storm activity (see *Note 7*).

f) radio frequency interference, internal noise & EW spoofing

Radio frequency interference was apparently not seriously considered by Blue Book. However a summary in the file of a phone conversation between Col. Werlich and an FTD officer contains the remark that according to Werlich "the blip changed shape, round, rectangular, etc". The conversation is dismissed as having contained "nothing of value", which may mean that oddly-mishapen blips are being considered diagnostic of false targets and that this information therefore adds "nothing of value" to what Blue Book had already concluded. A "rectangular" blip might reasonably have been thought to indicate some electronic artefact or interference, but there is nothing in the file that could be construed as an analysis of this possibility.

The *Phase B* echo recorded on the scope photos does vary in presentation, in a manner that can be construed as elongating or doubling in a radial direction and reverting on 782 to a more compact blip before disappearing. The meaning of "rectangular" is not very clear and may refer to a verbal description offered by the operator in respect of some earlier phase of the incident, or it may refer to the sort of appearance visible in frame # 776. Here the doubled or ghosted echo appears flattened off at the far end where it merges into the range ring, and at a glance it perhaps does resemble a somewhat rectangular "bar". But although these aspects of the presentation are certainly unusual, they are not necessarily diagnostic of an electronic phantom. There are mechanisms that could cause such effects to occur when the radar is detecting an ordinary reflective object (see *Sections 6.k* & *6.l* below). In fact this sort of fairly discrete blip is far from the most likely appearance of an RFI display product. Spiral or spoke-like patterns all over the scope are typical.

When powerful radar pulses with foreign characteristics, or powerful continuous wave emissions that are not pulse modulated like radar beams, are picked up throughout the receiving antenna's rotation *via* sidelobe and spillover gain (or sometimes when a noise source washes directly through poorly shielded receiver circuitry) the display products are usually scrambled because the receiver input bears no relation to the specific modulation for which the display timebase is designed. But it is possible in a special case for interference to emulate a target arc if signals closely comparable to a radar's normal output can be picked up from a similar remote radar only *via* the antenna main gain - i.e., when the radars are "looking" at each other.

The conditions are: *a*) for the two radar wavelengths to be closely matched; *b*) for both scan rates to be closely matched; *c*) for both p.r.f's to be very closely matched; and *d*) for a short pulse train to be rather discretely sampled, which probably requires *e*) that the two antenna rotations are synchronised 180 degrees out of phase, so that they "look at each other" once per scan whilst sweeping in opposite directions and the simulated "dwell time" is short, and/or *f*) that there is a highly spatially anisotropic radio duct in the atmosphere that helps by sampling only the strong pulses at the peak of the gain. (There are also anti-ECM sidelobe suppression techniques commonly used in airborne radars that might enhance this selectivity; the ACR version of this radar did have monopulse sidelobe reduction or MSR, but the Tech Order suggests that it was only usable by selecting a distinct anti-jamming mode of the ACR, so it would probably not affect the situation in Station Keep.)

If all of the conditions are satisfied the display product might resemble the discrete arc of pulses returned from a point target. If we consider two fixed ground radars, then if the two scan rates are perfectly synchronous the "echo" would appear in the same place on each scan, a stationary target. If the scan rates are very slightly asynchronous by an amount shorter than the trace time (which is the light-travel time for the maximum range on the display, about 0.5 millisecond for a 100 mile range) then the echo can progress radially in or out, along approximately the same set of trace radii, varying in intensity and presentation as the two antennas drift towards or away from perfect boresight alignment. But if the asynchrony per rotation is larger than the trace time then the blip won't progress smoothly but will skip around, first on the range axis and then in azimuth as well.

Obviously problems of interference that can be anticipated are normally designed out. Transmitters are tunable and identical sets are not normally sited in the radar line of sight from one another. Nevertheless RFI does occur, and it could happen that two very distant similar radars are able to "see" each other on rare occasions due to anomalous propagation conditions. There are large numbers of off-the-shelf civil and military ATC, airfield surveillance or GCA radar sets in use at airfields large and small across the US, as well as air navigation and weather radars. It is easy to imagine that a false near-stationary target could sometimes be caused by unusual mutual interference between two closely matched radars.

On the other hand this X-band airborne bombing-navigation radar differs from common L-band or S-band surveillance sets, and in the present case we know that at least one of the two radars hypothetically involved is an airborne bombing radar travelling at ~250 knots almost tangentially to an hypothetical line of sight whose bearing from the 1st radar definitely does not change at all within the limits of measurement for 24 seconds (scope photos 773-781), and probably does not change very substantially for around 5 minutes (contemporary witness reports). This could mean either *a*) that the source radar is so remote that the angular displacement is negligible even at the ground speed of the B-52, or *b*) that the source radar is also mobile.

The first option might just be supportable for the duration of the extant photos. For example: assume the true bearing is known within error bars of +/-1.0 degree, compounded of an uncertainty of +/-0.5 degree in the PPI bearing indication and a similar uncertainty in the aircraft heading/yaw indication (this may be optimistic). Then 24 secs. flight at 250 mph gives a travel of about 1.66 miles, which would subtend an angle narrower than 1.0 degree from a remote radar at any range greater than ~100 miles.

But a remote fixed ground radar would probably be in conflict with witness testimony, which indicates a duration of target-stationing off the left wing approaching 6 minutes. Distance to the radar would need to be more than about 1400 miles to keep the angular displacement within 1.0 degree in this case, which is around 5 times the maximum unambiguous range of the ASB-9 and in the order of 10 times the radar horizon distance from the B-52 at the time of the photography, implying a relatively powerful radar and trapping or ducting conditions for which there is no evidence (see *Section 6.k*).

It is true that we lack photo evidence that the echo bearing remained constant to the same accuracy during the entire 6 minutes. If it moved 10 degrees in this time then the emitting radar could have been as close as the second-trip distance of 140 miles. And many types of radars, such as marine radars, some weather radars, fire-control radars or army mobile tactical radars, share the X-band frequency range of the ASB-9. But arguably by far the most likely candidate for an emitter that meets all the conditions of precisely similar frequency, pulse repetition frequency and scan rate, and which also enables the echo to remain at a constant bearing from a moving receiver over an arbitrary period, is another airborne ASB-9 bombing-navigation radar, presumably in another B-52 flying a parallel course many tens of miles away to the NE.

Conceivably, a high level radio duct above the levels sampled by radiosonde could cause some energy to arrive *via* slightly longer refracted ray paths as a fractionally delayed ghost of the main signal, recieved by standard 4/3-earth radius ray paths, and it is possible that this could explain the elongation of the blip along the range axis of the PPI, with a fainter secondary blip appearing intermittently.

There is also a strong direct correlation between the rate of closure of the *Phase B* blip on the display and the rate of descent of the B-52 (see *Section 7*). Now, if there is relative movement between the transmitting and receiving radars, and/or a fluctuating ray path due to anomalous refraction, then the length of the ray path may change and the receiver will "see" this as a changing echo delay. Conceivably, therefore, a change in displayed range could be systematically related to the aircraft altitude.

But *ex hypothesi* the interference display product on the PPI has an extremely sensitive dependency on the degree of asynchrony in the two radars' intrinsic electromechanical periodicities. The asynchrony has to be tiny in order to produce a display product resembling a discrete echo in the first place; but in order for the change in its displayed range to be overwhelmingly dominated by a changing length of ray path systematically related to the altitude, any underlying blip displacement due to drift in the two antenna rotation rates (in particular) would need to be vanishingly small, approaching microsecond synchrony.

This seems highly unlikely, even assuming identical radar installations. Indeed, especially assuming this: The ASB-9 antenna is driven by a hydraulic motor whose nominal 20 RPM rate is specified in the Tech Order as 17.5 - 22.5 RPM, margins of +/- 12.5%, leading to a *possible* 25% (5RPM) disrepancy in the rotation rates of two otherwise identical ASB-9 radars, or as much as 0.75 sec per 3-second scan period. In fact the radarscope clock in the photos gives evidence that this antenna rotation rate is slightly adrift from its nominal 20 RPM setting and has an error of possibly about 2% (see *Section 2* and *Note 3*) which, if correct, would limit the total possible discrepancy to somewhere in the range 10.5% - 14.5% depending on whether the two drifts add or subtract, or about 0.3 - 0.4 sec per rotation. Since even a discrepancy ten times as small as this would still be three orders of magnitude too large, we should probably conclude that a systematic reference to the local flight level is more naturally explainable if the displayed range represents a genuine echo delay from some nearby reflector having an approximately constant relation to the ground level (such a model is developed in *Section 7*).

But several facts can be brought forward to suggest that there was something unusual about the electromagnetic environment. The B-52 navigator, Pat McCaslin, recalls that the plane' s Electronic Warfare officer received unusual responses on his equipment during the time that the unidentified echo was being detected (although this does not appear in the Blue Book documents and is not recalled by Goduto). UHF radio transmission from the aircraft is also known to have been affected during the same period. The possibility arises that these electromagnetic anomalies are symptoms of a deliberate ECM jamming exercise carried out against the B-52 by other elements of the USAF. But if the intention is to simulate a convincing aircraft target then this deception jamming (from an unidentified source; see also *Section 6.b*) was not a very effective spoof. Also, jamming does not simply silence radio transmissions, as was described in this case, but fills the frequency band with noise; and how would it block UHF transmissions selectively but not block UHF reception on the same (multiple) radio sets?

Finally there is the possibility of internal radar system noise due to component degradation or something similar. There is no evidence in the file that any internal radar fault was discovered, or even suspected, either by the operators or by investigators in the ensuing days and weeks. There is no specific record of an electronics check (part of the reason for this may have been the undismissable ground- and air-visual reports as well as the report of a target on the electronically independent Minot weather radar) but presumably neither routine operations nor maintenance uncovered any persistent fault.

The Blue Book investigation does nevertheless seem to have considered the idea that an electronic fault implicated in the UHF failure might somehow have caused the radar blip (no mention of the EW equipment responses occurs in the file), but this was discarded quite quickly. Col. Werlich satisified himself that the UHF hiatus was not due to an equipment fault - the transmission was suddenly interrupted "in the middle of a word", affecting both independent UHF sets, and both sets worked perfectly afterwards. If the radar blip was an internal noise track, or remote interference, then in either case there is a pure coincidence with the UHF interruption. Blue Book' s reasoning seems to have been that it was better to seek a common external cause of the radar blip and the UHF interruption, hence the reliance on "ball lightning". The logic of this position is probably sound even if the explanation isn't.

In summary, interference from another B-52 bombing-navigation radar may be physically possible, but the operators had seen nothing like this before, neither had the radarscope photoanalysts, so presumably it must be very rare. Hypothetical propagation conditions might help to account for this, but still the combination of special circumstances required is undeniably very fortuitous. Simultaneous UHF failure and air/ground visual observations add further levels of coincidence. The scenario is at least very improbable.

g) balloon

The Blue Book file mentions that Lt. Marano raised the possibility of hot-air balloons as an explanation of the sightings. There is also some ambiguous reference to "trouble we have had with hot air balloons" although the context of this remark is very unclear. This notion was dismissed by Col.Werlich on the grounds of local geography and the fact that there were only handful of remote farmhouses in hundreds of square miles. Whether Marano was offering this idea to explain the radar echoes as well as the air- and ground-visual sightings is not clear, but it should be considered. The copilot's description of the grounded object as an orange-glowing oval, with a "molten", "translucent" look to it and a greenish appendage on one end, could (with some effort, it has to be said) be squared with a very large hot-air balloon.

Obvious objections are the implied radar cross-section of the "balloon" and its velocity. In the case of a hot air balloon it is interesting to speculate that the flame and/or associated turbulent hot air column might themselves contribute to the radar signature, and one might imagine the intermittent "doubling" of the radar target as indicating a constant echo from the bulk of a balloon somewhat below the B-52, supplemented with an occasional secondary echo at slightly greater slant range when the flame generator below it is switched on. But the height of the rig implied by the displayed range differential between "balloon" and "gondola" (order of 1000 ft) would be unrealistic. And in any case balloon envelopes are generally not radar reflective, implying that the constant echo would have to come from conductive components in the payload, with the intermittent echo at greater displayed range being caused by the flame and hot air column rising into the envelope above it. But this would have to mean that the rig was considerably *above* the B-52's probable altitude of about 9000 ft and implies that it disappeared in frame 782 by *climbing* out of the radiation pattern, not by descending to the ground, which is contrary to the reported "landing" scenario that presumably gave rise to Lt. Marano's hot-air balloon speculation in the first place. And a radar cross-section comparable to a large jet is wholly inconsistent with any believable balloon payload.

As for relative velocity: The range rate and the azimuth rate of the *Phase B* echo relative to the B-52 are very small. Winds from 320 degrees would be directly behind the B-52, but obviously the vector sum of the highest likely rate of balloon ascent (say about 15 mph) and a 50-knot wind (the strongest winds at *any* altitude of the aircraft during the incident, @ 20,000 ft) cannot remotely match the likely aircraft ground speed. If a near co-altitudinal balloon falls behind the B-52 at a plausible rate of 140 knots then during the 24 second *Phase B* photograph sequence the bearing to the balloon should drop back by some 30 degrees. The bearing of the radar echo changes only 1 degree between frames 773 and 782. The relative angular rate alone seems sufficient to rule out a balloon as a cause of the radar episode.

h) auroral ionisation

Blue Book makes only passing mention of auroral phenomena. Discussing lightning plasmas that might cause electrical effects and be detected on radar, Quintanilla adds the remark that "Aurora Borealis is quite often seen from Minot AFB at this time of the year and is an electrical atmospheric phenomenon", apparently implying in a vague way that auroral phenomena might be stirred into the explanatory mix.

Auroral ionisation can reflect radio waves and generally does so in an echo pattern that correlates quite closely with the visual pattern of the auroral glow, i.e. in broad swathes and streaks spanning many degrees of arc. It might in some cases cause discrete small echoes on some radar scopes but this seems most unlikely in the present case. Neither of the echoes on frames 771 and 772 is likely to be due to aurora since *a*) neither echo is in the auroral quadrant and *b*) detectable auroral echoes at 3cm are very unlikely anyway because the frequency dependency of auroral echoes is similar to that of other ionisation phenomena such as meteor trails and lightning channels.

The true ranges to aurorae will be comparable to the ranges of most meteors, in the order of hundreds of miles at low elevations (therefore multiple trip echoes), and the electron densities will be much lower than in meteor trails. Power reflectivity from ionisation falls off rapidly through L-band and S-band, and an X-band radar such as ASB-9 has little chance. Metric wavelengths in the order of 100 times the 3cm length of the ASB-9 are favoured.

The condition for detection is further crucially restricted by the need for the radar line of sight to be near perpendicular to the magnetic field lines, which generally limits echoes to a well-defined region in the N scope quadrant, regardless of where in the sky visual auroras may be observable. The radar' s angle of elevation in this case is not very high, being under the nose of the B-52, and from a simple geometric point of view the antenna would be extremely poorly placed for detecting zenithal auroral streamers even if the streamer orientation and radar wavelength were favourable.

In short, the *Phase A* radar echoes in the southerly scope sectors (771 & 772) are almost certainly not auroral echoes on the grounds of magnetic field geometry alone, and the *Phase B* echo is very probably not an auroral echo on the grounds of its discreteness, strength, stability in the same approximate location, and persistence at a very unfavourable radar wavelength.

i) birds, insects

The persistence of the *Phase B* echo at a 40 degree bearing from a B-52 flying on a straight heading at ~250 knots seems sufficient to rule out birds or insects.

Could birds account for the *Phase A* echoes to the right of the plane on frames 771 and 772? Obviously a single bird is ruled out. It is also difficult to conceive of two different birds each rapidly flying in and out of the radar cover for a single scan, especially given evidence in each echo of internal structure indicating either a very high target rate during the brief dwell time of the beam or an elongated target echoing area with a major axis in the order of hundreds of feet (see *Section 7*).

It might be worth pointing out that larger birds at ranges of just a couple of miles could be bright targets. In fact the inverse 4th power attenuation of echo intensity means that on a normal PPI showing airborne targets out to the limit of the display a nearby bird can be a stronger target than a distant aircraft on the same scan, possibly deceiving an inexperienced operator. But this is not a normal surveillance PPI used (generally) to search for targets out to long ranges. The operator is only looking at airborne targets inside a small altitude "hole" whose maximum radius is never more than about 30,000 ft, and in terms of range he is broadly speaking always comparing like with like. For example, the ratio of returned power between identical targets at 4 miles and 1 mile range inside the 5-mile Station Keep PPI display is only 1 **:** 256, which is very tiny compared to the ratio of signal levels handled by a typical ground-based surveillance radar and comparable to the variation in return from a single aircraft due to changing aspect. By contrast, two identical targets at 50 miles and 1 mile range inside a 60-mile airfield surveillance PPI would have an enormous signal ratio of 1 **:** 6.25 x 10^6. In the present case an experienced radar-navigator accustomed to the use of the ASB-9 radar for close-range Station Keeping on refuelling tankers offered the view that the *Phase B* echoes indicated a target cross section larger than a KC-135 at comparable range. This is confirmed by the opinion of the Bomb Wing intelligence analyst based on the radarscope photos.

It is possible for a cloud of insects to produce a significant target, indeed the more so at X-band than at more typical surveillance wavelengths. But the issues raised with regard to bird echoes become even more grossly problematic for insects. Therefore neither of these common sources of radar "angels" seems to be relevant on the grounds of implied airspeed and echo intensity and presentation.

j) satellites

First-trip echoes from satellites at high elevations within the unambiguous range of the radar (67.5 miles in Station Keep mode) are ruled out by a maximum top edge main beam coverage of only +8 degrees. In any case the speeds and trajectories would be very inappropriate. However the radar could in principle pick up multiple-trip echoes from a distant satellite at low angles of elevation. In this case displayed tangential speeds would be slowed and the track of a satellite in a polar orbit travelling N-S roughly perpendicular to the radar line of sight could be distorted into a curve or a "V" approaching and receding from the scope centre. But there seems to be no sensible application of the theory in this case.

Large satellites at this date could have cross-sections of hundreds of square meters, as large as or larger than a well-aspected big jet. But the inverse 4th-power attenuation of returned energy makes the effect of distance dramatically nonlinear, and it seems inconceivable that any satellite at likely third-trip ranges could present as an echo which was characterised by experienced operators and photoanalysts as stronger than that from a nearby B-52 or "several times the size of KC-135 tanker".

Also, although the apparent groundspeed indicated on the PPI would be several times slower than the typical ~18,000 mph orbital speed the average angular rate would be preserved. This rate will typically be in the order of 100 degs/minute. The angular rate of the persistent *Phase B* echo is near-zero for far too long. The recorded angular rate over almost half a minute is less than about 2 degs/minute. This is already inconsistent with a satellite echo and testimony indicates that a comparably low angular rate was maintained for several minutes before the camera was switched on.

Finally the displayed range rate of a multiple-trip satellite echo would still be in the order of 1000' s of mph, but photo and witness evidence both indicate a negligible range rate maintained for at least tens of seconds and probably for several minutes.

In short, satellite echoes appear to be ruled out.