cloudy atmosphere would discourage astronomy, hence space travel. The remaining Solar planets are such poor prospects that they can be ignored.

In the next few paragraphs, we shall speak of Mars. It should be understood that most of the remarks apply equally well to Venus.

Various people have suggested that an advanced race may have been visiting Earth from Mars or Venus at intervals from decades to eons. Reports of objects in the sky seem to have been handed down through the generations. If this were true, a race of such knowledge and power would have established some form of direct contact. They could see that Earth's inhabitants would be helpless to do interplanetary harm. If afraid of carrying diseases home, they would at least try to communicate. It is hard to believe that any technically accomplished race would come here, flaunt its ability in mysterious ways and then simply go away. To this writer, long-time practice of space travel implies advanced engineering and science, weapons and ways of thinking. It is not plausible (as many fiction writers do) to mix space ships with broadswords. Furthermore, a race which had enough initiative to explore among the planets would hardly be too timid to follow through when the job was accomplished.

One other hypothesis needs to be discussed. It is that the Martians have kept a long-term routine watch on Earth and have been alarmed by the sight of our A-bomb shots as evidence that we are warlike and on the threshold of space travel. (Venus is eliminated here because her cloudy atmosphere would make such a survey impractical). The first flying objects were sighted in the Spring of 1947, after a total 5 atomic bomb explosions, i.e., Alamogordo, Hiroshima, Nagasaki, Crossroads A and Crossroads B. Of these, the first two were in positions to be seen from Mars, the third was very doubtful (at the edge of Earth's disc in daylight) and the last two were on the wrong side of Earth. It is likely that Martian astronomers, with their thin atmosphere, could build telescopes big enough to see A-bomb explosions on Earth, even though we were 165 and 153 million miles away, respectively, on the Alamogordo and Hiroshima dates. The weakest point in the hypothesis is that a continual, defensive watch of Earth for long periods of time (perhaps thousands of years) would be dull sport, and no race that even remotely resembled Man would undertake it. We haven't even considered the idea for Venus or Mars, for example.

The sum and substance of this discussion is that if Martians are now visiting us without contact, it can be assumed that they have just recently succeeded in space travel and that their civilization would be practically abreast of ours.

The chance that Martians, under such widely divergent conditions, would have a civilization resembling our own is extremely remote. It is particularly unlikely that their civilization would be within a half century of our own state of advancement. Yet in the last 50 years we have just started to use aircraft and in the next 50 years we will almost certainly start exploring space.

Thus it appears that space travel from another point within the Solar system is possible but very unlikely. Odds are at least a thousand-to-one against it.

This leaves the totality of planets of other stars in the Galaxy as possible sources. Many modern astronomers believe that planets are fairly normal and logical affairs in the life history of a star (rather than cataclysmic oddities) so that many planets can be expected to exist in space.

To narrow the field a little, some loose specifications can be written for the star about which the home base planet would revolve. Let us say that the star should bear a family resemblance to the Sun, which is a member of the so-called "main-sequence" of stars, i.e., we eliminate white dwarfs, red giants and supergiants. For a description of these types, see reference 2, chapter 5. There is no specific reason for making this assumption except to simplify discussion: we are still considering the majority of stars.

Next, true variable stars can be eliminated, since conditions on a planet attached to a variable star would fluctuate too wildly to permit life. The number of stars deleted here is negligibly small. Reference 3, pages 76 and 85 indicate that the most common types are too bright to be in nearby space unnoticed. Lastly, we shall omit binary or multiple stars, since the conditions for stable planet orbits are obscure in such cases. About a third of the stars are eliminated by this restriction.

As our best known sample of space we can take a volume with the Sun at the center and a radius of 16 light years. A compilation of the 47 known stars, including the Sun, within this volume is given in reference 4, pages 52 to 57. Eliminating according to the above discussion: Three are white dwarfs, eight binaries account for 16 stars and two trinaries account for 6 more. The remainder, 22 stars, can be considered as eligible for habitable planets.

Assuming the above volume to be typical, the contents of any other reasonable volume can be found by varying the number of stars proportionately with the volume, or with the radius cubed, $S_e = 22 \times (\frac{r}{16})^3$, where S_e is number of eligible stars and r is the radius of the volume in light years. (This formula should only be used for radii greater than 16 light years. For smaller samples we call for a recount. For example, only one known eligible star other than the Sun lies within eight light years).

Having an estimate of the number of useable stars, it is now necessary to make a guess as to the number of habitable planets. We have only one observed sample, the Solar System, and the guess must be made with low confidence, since intelligent life may not be randomly distributed at all.

The Sun has nine planets, arranged in a fairly regular progression of orbits (see reference 1, Appendix I) that lends credence to theories that many stars have planets. Of the nine planets, (one, the Earth) is completely suitable for life. Two more (in adjacent orbits) are near misses: Mars has extremely rigorous living conditions and Venus has an unsuitable atmosphere. Viewed very broadly indeed, this could mean that each star would have a series of planets so spaced that one, or possibly two, would have correct temperatures, correct moisture content and atmosphere to support civilized life. Let us assume that there is, on the average, one habitable planet per eligible star.

There is no line of reasoning or evidence which can indicate whether life will actually develop on a planet where the conditions are suitable. Here again, the Earth may be unique rather than a random sample. This writer can only inject some personal intuition into the discussion with the view that life is not unique on Earth, or even the random result of a low probability, but is practically inevitable in the right conditions. This is to say, the number of inhabited planets is equal to those that are suitable!

One more item needs to be considered. Knowing nothing at all about other races, we must assume that Man is average as to technical advancement, environmental difficulties, etc. That is, one half of the other planets are behind us and have no space travel and the other half are ahead and have various levels of space travel. We can thus imagine that in our sample volume there are 11 races of beings who have begun space explorations. The formula on page 3 above now becomes

$$R = 11 \times (\frac{r}{16})^3$$

where R is the number of races exploring space in a spherical volume of radius $r \geq 16$ light years.

Arguments like those applied to Martians on page 2 need not apply to races from other star systems. Instead of being a first port of call, Earth would possibly be reached only after many centuries of development and exploration with space ships, so that a visiting race would be expected to be far in advance of Man.

To summarize the discussion thus far: the chance of space travelers existing at planets attached to neighboring stars is very much greater than the chance of space-traveling Martians. The one can be viewed almost as a certainty (if the assumptions are accepted), whereas the other is very slight indeed.

In order to estimate the relative chances that visitors from Mars or star X could come to the Earth and act like "flying objects", some discussion of characteristics of space ships is necessary.

To handle the simple case first, a trip from Mars to Earth should be feasible using a rocket-powered vehicle. Once here, the rocket would probably use more fuel in slowing down for a landing than it did in initial takeoff, due to Earth's higher gravitational force.

A rough estimate of one-way performance can be found by adding the so-called "escape velocity" of Mars to that of the Earth plus the total energy change (kinetic and potential) used in changing from one planetary orbit to the other. These are 3.1, 7.0, and 10.7 miles per second, respectively, giving a total required performance of 20.8 miles per second for a one-way flight. Barring a suicide mission, the vehicle would have to land and replenish or else carry a 100% reserve for the trip home.

Let us assume the Martians have developed a nuclear, hydrogen-propelled vehicle (the most efficient basic arrangement that has been conceived here on Earth) which uses half its stages to get here and the remaining stages to return to Mars, thus completing a round trip without refueling, but slowing down enough in our atmosphere to be easily visible (i.e., practically making a landing). Since it is nuclear powered, gas temperatures will be limited to the maximum operating temperatures that materials can withstand (heat must transfer from the pile to the gas, so cooling can't be used in the pile). The highest melting point compound of uranium which we can find is uranium carbide. It has a melting point of 4560°R. Assume the Martians are capable of realizing a gas temperature of 4500°R (= 2500°K), and that they also have alloys which make high motor pressures (3000 psi) economical. Then the specific impulse will be I = 1035 seconds and the exhaust velocity will be c = 33,400 ft/sec (reference 5). Calculation shows that using a single stage for each leg of the journey would require a fuel/gross weight ratio of 0.96 (for each stage) too high to be practical. Using two stages each way (four altogether) brings the required fuel ratio down to 0.81, a value that can be realized.

If, by the development of strong alloys, the basic weight could be kept to 10% of the total weight for each stage, a residue of 9% could be used for payload. A four stage vehicle would then have a gross weight $\left(\frac{100}{9}\right)^4$ = 15,000 times as great as the payload: thus, if the payload were 2,000 pounds, the gross weight would be 30 million pounds at initial takeoff (Earth pounds).

Of course, if we allow the Martians to refuel, the vehicle could have only two stages* and the gross weight would be only $\left(\frac{100}{9}\right)^2 = 123$ times the payload, i.e., 250,000 pounds. This would require bringing electrolytic and refrigerating equipment and sitting at the South Pole long enough to extract fuel for the hourney home, since they have not asked us for supplies. Our oceans (electrolysis to make H_2) would be obvious to Martian telescopes and they might conceivably follow such a plan, particularly if they came here without foreknowledge that Earth has a civilization.

Requirements for a trip from a planet attached to some star other than the Sun can be calculated in a similar manner. Here the energy (or velocity) required has more parts: (a) escape from the planet (b) escape from the star (c) enough velocity to traverse a few light years of space in reasonable time (d) deceleration toward the Sun (e) deceleration toward the Earth. The nearest "eligible" star is an object called Wolf 359 (see reference 4, p 52), at a distance of 8.0 light years. It is small, having an absolute magnitude of 16.6 and is typical of "red dwarfs" which make up more than half of the eligible populations. By comparison with similar stars of known mass, this star is estimated to have a mass roughly 0.03 as great as the sun. Since the star has a low luminosity (being much cooler and smaller than the Sun) a habitable planet would need to be in a small orbit for warmth.

Of the changes of energy required as listed in the preceding paragraph, item (c), velocity to traverse intervening space, is so large as to make the others completely neglibible. If the visitors were long lived and could "hibernate" for 80 years both coming and going, then 1/10 the speed of light would be required, i.e., the enormous velocity of 18,000 miles per second. This is completely beyond the reach of any predicted level of rocket propulsion.

If a race were far enough advanced to make really efficient use of nuclear energy, then a large part of the mass of the nuclear material might be converted into jet energy. We have no idea how to do this, in fact reference 6 indicates that the materials required to withstand the temperatures, etc., may be fundamentally unattainable. Let us start from a jet-propellant-to-gross-weight ratio of .75. If the total amount of expended material (nuclear plus propellent) can be .85 of the gross weight, then the nuclear material expended can be 0.10 of the gross. Using an efficiency of 0.5 for converting nuclear energy to jet energy and neglecting relativistic mass corrections, then a rocket velocity of half the velocity of light could be attained. This would mean a transit time of 16 years each way from the star Wolf 359, or longer times from other eligible stars. To try to go much faster would mean spending much energy on relativistic change in mass and therefore operating at lowered efficiency.

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* Actually three stages. On the trip to Earth, the first stage would be filled with fuel, the second stage would contain partial fuel, the third would be empty. The first stage would be thrown away during flight. On the trip back to Mars, the second and third stages would be filled with fuel. The gross weight of the initial vehicle would be of the order of magnitude of a two-stage rocket.

To summarize this section of the discussion, it can be said that a trip from Mars is a logical engineering advance over our own present technical status, but that a trip from another star system requires improvements of propulsion that we have not yet conceived.

Combining the efforts of all the science-fiction-writers, we could conjure up a large number of hypothetical methods of transportation like gravity shields, space overdrives, teleports, simulators, energy beams and so on. Conceivably, among the myriads of stellar systems in the Galaxy, one or more races have discovered methods of travel that would be fantastic by our standards. Yet the larger the volume of space that must be included in order to strengthen this possibility, the lower will be the chance that the race involved would ever find the earth. The Galaxy has a diameter of roughly 100,000 light years and a total mass about two hundred billion times that of the Sun (reference 4). Other galaxies have been photographed and estimated in numbers of several hundred million (reference 2, p. 4) at distances up to billions of light years (reference 7, p 158). The number of stars in the known universe is enormous, yet so are the distances involved. A super-race (unless they occur frequently) would not be likely to stumble upon Planet III of Sol, a fifth-magnitude star in the rarefied outskirts of the Galaxy.

A description of the probable operating characteristics of space ships must be based on the assumption that they will be rockets, since this is the only form of propulsion that we know will function in outer space. Below are listed a few of the significant factors of rocketry in relation to the "flying objects".

(a) Maneuverability. A special-purpose rocket can be made as maneuverable as we like, with very high accelerations either along or normal to the flight path. However, a high-performance space ship will certainly be large and unwieldy and could hardly be designed to maneuver frivolously around in the Earth's atmosphere. The only economical maneuver would be to come down and go up more or less vertically.

(b) Fuel reserves. It is hard to see how a single rocket ship could carry enough extra fuel to make repeated descents into the Earth's atmosphere. The large number of flying objects reported in quick succession could only mean a large number of visiting craft.

Two possibilities thus are presented. First, a number of space ships could have come as a group. This would only be done if full-dress contact were to be established. Second, numerous small craft might descend from a mother ship which coasts around the Earth in a satellite orbit. But this could mean that the smaller craft would have to be rockets of satellite performance, and to contain them the mother ship would have to be truly enormous.

(c) Appearance. A vertically descending rocket might well appear as a luminous disk to a person directly below. Observers at a distance, however, would surely identify the rocket for what it really is. There would probably be more reports of oblique views than of end-on views. Of course, the shape need not be typical of our rockets; yet the exhaust should be easy to see.

One or two additional general remarks may be relevant to space ships as "flying objects". The distribution of flying objects is peculiar, to say the least. As far as this writer knows, all incidents have occurred within the United States, whereas visiting spacemen could be expected to scatter their visits more or less uniformly over the globe. The small area covered indicates strongly that the flying objects are of Earthly origin, whether physical or psychological.

The lack of purpose apparent in the various episodes is also puzzling. Only one motive can be assigned; that the space-men are "feeling out" our defenses without wanting to be belligerent. If so, they must have been satisfied long ago that we can't catch them. It seems fruitless for them to keep repeating the same experiment.

Conclusions:

Although visits from outer space are believed to be possible, they are believed to be very improbable. In particular, the actions attributed to the "flying objects" reported during 1947 and 1948 seem inconsistent with the requirements for space travel.

Very truly yours,

J. E. Lipp
Missiles Division

JEL:sp

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APPENDIX F

3410th Electronics Station

Analysis of Project Grudge Reports

ACT/Be

AIR MATERIEL COMMAND
3160 Electronics Station
Cambridge Field Station
230 Albany Street
Cambridge 39, Mass.

000.92
In reply address both communication and envelope to the Commanding Officer and attention of following office symbol. ERH

April 18, 1949

SUBJECT: Analysis of Project "Grudge" Reported Incidents

TO: Commanding General
Air Materiel Command
Wright-Patterson Air Force Base
Dayton, Ohio
ATTN: MCIAXO

1. Reference is made to the letters from your Headquarters to this station of 22 November 1948, 6 December 1948, and 14 January 1949, Subjects: "Project 'Sign' ", requesting that reported incidents 1 through 172 be analysed to determine whether or not these might have been caused by balloons launched by these laboratories.

2. A listing has been compiled of all balloons launched by these laboratories and its contractors for special atmospheric research purposes, from the first such launching to No. 101 on 17 November 1948. Each of these launchings has been compared with the reported incidents 1 through 172. Factors of comparison were date of launching and date of recovery with respect to date of reported incidents; place of launching and place of recovery with respect to the place of reported incidents, and possible deviations from the known flight path with respect to the place of reported incidents. So that your office may make an independent analysis, three copies of the launching list are inclosed.

a. Incidents No. 5 through No. 16 reported on 4 July 1947 throughout Oregon, Idaho and Washington gave, in general, descriptions of clusters or groups of objects. The 3 July 1947 balloon launching No. 8 at Alamogordo was a cluster of balloons and was not recovered, and so might be suspected of being the cause of these reports. However, although not recovered, this flight was terminated in the New Mexico Tularosa Valley only a few miles northwest of Alamogordo. That the balloons were downed was determined both by airplane spotting and by radio direction finding upon the balloon telemetering instruments. Recovery of the balloons and instruments was prevented by the impassability of the terrain.

b. Balloon release No. 11 of 7 July 1947 could compare with respect to date with incident No. 1 through No. 4, and again with incident No. 40. This balloon flight was again a cluster.

[redacted]

The description of incident No. 40 is inconsistent with the appearance of balloon flight No. 11. Also, in consideration of the prevailing upper winds, it is very unlikely that the balloons would have gone more than a few miles westward of Alamogordo, although it must be admitted that a long flight west of the launching point could not be ruled out as impossible.

c. Incident No. 47 compares somewhat in time with balloon Launching No. 10 of 5 July 1947. However, balloon No. 10 although not recovered was known to have been downed northeast of Albuquerque, New Mexico. It was not recovered due to impassability of terrain. Incident No. 113 is a reasonable description of the 20 ft. plastic balloon and instruments used by these Laboratories. This incident was on the date of balloon release No. 46 of 9 April 1948 at Alamogordo. However, the time of the reported incident (1506 CST) is about 1/2 hour before the time of balloon release (1432 MST), thus the incident could not have been that balloon.

d. It is of interest to note that incident No. 122 was reported by an employee of these Laboratories who had considerable experience in the use of balloons of all kinds, and could have been depended upon to know the appearance and behavior of a balloon if it was this he saw.

e. Incident No. 163 bears a fair description of the appearance of a large plastic balloon in sunset light. The object's disappearance could be accounted for either by its movement into the earth's sunset shadow or by natural defocusing of the observer's eyes. This incident could possibly have been balloon release No. 75 or No. 76 or 20 and 21 July 48 from Alamogordo. Balloon No. 75 was recovered at Hollister, California, which is in the Monterey Bay area, on 22 July 1948 and could have easily had a trajectory which would have been within sight of the Los Angeles area. Balloon No. 76 was never recovered. It is possible that it had a trajectory similar to No. 75.

f. All other reported incidents from 1 to 172 do not seem to have reasonable comparison with balloons launched by these Laboratories.

3. The balloons used by these Laboratories are now somewhat standardized. They are 20 feet long, plastic, white in color, and hea sphere-on-cone in shape. Nearly all launchings are made at the Holloman AFB at Alamogordo, New Mexico. Two photograph prints are inclosed showing the appearance and size of these balloons. The larger photograph shows the typical flight appearance at any altitudes where it would be visible. It is hoped that this information may be of some use to you in identifying future reports of incidents.

[redacted]

4. It is believed that certain of the items in the questionnaire "Checklist-Unidentified Flying Objects" produce insignificant and unreliable data from an observer. These are: 9. Distance of object from observer; 11. Altitude; 12. Speed; and 16. Size. For any unfamiliar object beyond the focal range of the human eyes (about 60 ft.), these four factors are mutually inter-dependent and therefore indeterminant unless at least one of them (and some observed angles) are known. Directly asking an observer about these indeterminants not only gets unreliable data but induces wild answers because the observer is led into making a statement about quantities for which he has no basis in fact. He will unconsciously assume knowledge of some one of these factors and so give incorrect information on all. That people (many of whom should know better) will arbitrarily give answers to two significant figures on these questions, which really cannot be answered at all, is proof of the unreliability of their information.

5. It is suggested that these four items on the questionnaire be replaced by questions which will yield answers possible of being independent facts in terms of the observer's best estimates of angles and time. From such data given by observers of the same object at two different places, a reliable calculated estimate could be made of the object's size, altitude, speed and path. These data should include:

a. An estimate of the angular size of the object. A quick but reasonable estimate can be made by comparing the angle subtended by the index finger held at arms length. The finger (7/8" wide) of an average man held at 26" to 30" (arms length) will subtend an angle of approximately two degrees. In this way angular size from about 1/2° to about 8° can be estimated.

b. The range of the object's flight in terms of the angle subtended by the observed path. If the object moves in a reasonably straight course it is important to observe the position at the beginning and the end of its course. After the flight has been completed a person can extend his arms toward the two points and also at 90° or 180° and by comparison estimate the angular extent of the flight. It is also important that information which will determine those directions relative to a compass point be given. If the angular course is associated with objects on the horizon, with roads, with the sun (if the time of day is also noted) or by the north star, the orientation can be rechecked at any later time.

c. The time required for the object to traverse the observed course. This is probably the most difficult estimate to make. Timing with a watch is the most satisfactory, but an observer is seldom prepared to do so. Seconds can be counted with good accuracy by saying, 1 "one flying saucer; two flying saucers, three flying saucers" ---etc. At a normal speaking speed. On the other hand it is not easy to count seconds and at the same time make all the other desirable observations. It must be remembered that when a person is excited his estimates of time are apt to be rather inaccurate.

d. Estimation of the elevation angle of the object. Almost all persons will overestimate elevation angles. This tendency can be reduced by the observer extending one arm vertically and the other horizontally to observe a 90° angle. The vertical arm can then be lowered to point to the observed object. In this way the observed angle can be compared with a 90° angle and a more accurate estimate obtained.

6. It is realised that it might not be possible for an observer to perform the opeations suggested in the preceding paragraph, during the period the object is sighted. If he would immediately reconsider what he saw and then estimate such measurements, he should be able to give quantitative answers accurate to at least 25%. In interrogating observers, they should also be asked to reconstruct their observations and then estimate these same factors. It is suggested that instructions for making such quick and estimated observations be given to weather observers, control tower operators, civil police, forest and fire rangers, and other such people who might have good chance of seeing
1 unidentified flying objects. If any information concerning unidentified flying objects is given to the public, instructions for reliable observation should be included.

7. This organization will be pleased to be of any further assistance required in connection with this matter.

FOR THE COMMANDING OFFICER:

3 Incls
1. List of balloons launched (in trip)
2. 8" X 10" photo print of plastic balloon
3. 4" X 5" photo print of plastic balloon

/s/ A. C. Trakowski, Jr.
A. C. TRAKOWSKI, JR.
Captain, USAF
Director, Base Directorate for Geophysical Research

[redacted]

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APPENDIX G

Dr. Paul M. Fitts

Psychological Analysis of Reports of Unidentified Aerial Objects

DOWNGRADED AT 12 YEAR INTERVALS; NOT AUTOMATICALLY DECLASSIFIED. DOD DIR 5200.10

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U. S. AIR FORCE
HEADQUARTERS, AIR MATERIEL COMMAND
ENGINEERING DIVISION

MEMORANDUM REPORT ON

No. of pages - 1

MCREXD9/PMF/maf

28 April 1949

SUBJECT: Psychological Analysis of Reports of Unidentified Aerial Objects

SECTION: Aero Medical Laboratory

SERIAL NO.: MCREXD-694-18D Expenditure Order No. 694-38

A. PURPOSE:

1. At the request of the Technical Intelligence Division, Intelligence Department, AMC, an analysis has been made, from a psychological point of view, of 212 investigations of persons reporting sightings of unidentified aerial objects.

B. FACTUAL DATA:

2. A report of this analysis is attached as Appendix A.

C. CONCLUSIONS:

3. It is concluded by the writer that there are sufficient psychological explanations for the reports of unidentified flying objects to provide plausible explanations for reports not otherwise explainable. These errors in identifying real stimuli result chiefly from inability to estimate speed, distance and size.

D. RECOMMENDATIONS:

4. Test the ability of pilots to estimate the course of a small lighted balloon while doing aerobatics with it at night. It is suggested that several pilots try to fly pursuit curves and collision courses on such targets at night and report accurately their sensations. It would be desirable, but probably impossible, to keep them from knowing the nature of the light source.

5. In all future reports of unidentified objects specify the location of object with reference to polar coordinates (direction and degrees above the horizon) rather than asking individuals to estimate distance. If possible, obtain an estimate of size in terms of the visual angle subtended by the object.

6. In all future investigations determine the angular position of the sun with respect to the unidentified object and the observer.

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Also determine the approximate time during which the object was in sight (this informationwas not available for more than half the reports).

Prepared by: Paul M. Fitts
PAUL M. FITTS, Ph.D.
Chief, Psychology Branch

Prepared by: Shirley C. Connell
SHIRLEY C. CONNELL
Psychology Branch

Approved by: A.P. Gagge
A. P. GAGGE, Lt. Col., MSC (USAF)
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Chief, Aero Medical Laboratory

Distribution:

MCIAXS (2)

MCREXD9 (2)

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Engineering Division
Memorandum Report No. MCREXD-694-18D
28 April 1949

UNCLASSIFIED

APPENDIX A

PSYCHOLOGICAL ANALYSIS OF REPORTS OF

UNIDENTIFIED AERIAL OBJECTS

I

The Inaccuracy of Human Observation

Psychologists have long know that human perception is fallible. In fact, part of the science of psychology is concerned with the measurement of errors of observation, and with the discovery of the conditions and laws that govern such phenomena.

Errors of observation may be classified as variable or constant. Variable errors are those in which a number of separate observations are found to differ from one another. The distribution of such errors often follows the normal probability curve. Constant errors are those in which observations are consistently biased in one or another direction. For example, individuals often are guilty of a constant error, in the direction of underestimation, in reporting their ages.

Errors of observation may be classified further as precision errors and identification errors. Inaccuracy in estimating the speed of an aircraft is an example of the former. Mistaking an aircraft for a "flying saucer" is an example of the latter.

It is the purpose of the present report to analyse 212 reports of observations of unidentified flying objects in order to see to what extent these reports can be explained in terms of known psychological facts and principles.

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Scientific Method and a Posteriori Data

A word of caution must be injected at the outset of this report. Certain conditions are necessary for drawing valid scientific conclusions.

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These conditions are largely lacking in the case of the data available on unidentified flying objects. It is impossible to say with any assurance what any particular individual in this series of 212 reports was actually observing at any particular time. It is only possible to examine the accumulation of available evidence or the accumulation of all reports of a given class (e.g., all reports from supposedly competent observers) and to consider them in a statistical sense. If certain characteristics appear repeatedly in reports from different people it may be possible to infer causal factors.

It will never be possible, on the other hand, to say with certainty that any given observer could not have seen a space ship or an enemy missile, or some other object. It will only be possible to estimate the probability that he could have seen such things.

The principal hypothesis to be examined in the following discussion is that reports of unidentified flying objects have the characteristics that would be expected if they were cases of failure, on the part of typical normal individuals, to identify common or familiar phenomena.

Possible Sources of Inaccurate Reports of Flying Objects

There are three broad classes of mistakes in human observations. These are the following: 1. Misinterpreting the nature of real stimuli, 2. Mistaking unreal (imaginary) stimuli for real ones, and 3. Deliberate falsifications. Each of these are considered briefly below.

(1) Errors in Identifying Real Stimuli. All normal, intelligent people experience certain errors of observation. The moon appears much larger on the horizon than when it is high in the sky. A stick looks bent when one end is in water. Distant objects appear relatively close in clear, desert atmosphere. A small point-source of light, if viewed in a dark room, will appear to move about in strange gyrations, even [redacted]. This is called

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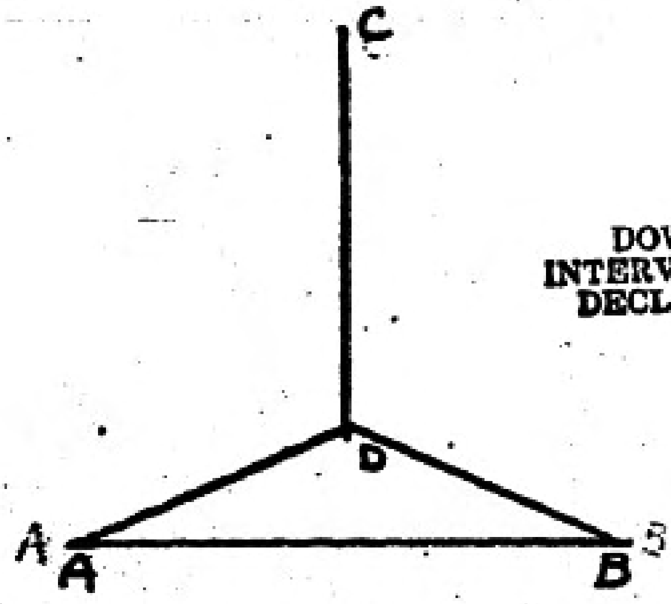
the autokinetic illusion (see Guilford, J. P., 1928). In the accompanying figure the line AB looks approximately as long as the line CD, but when you measure them the two will be found to be of quite different lengths.



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Visual stimuli originating within the eye itself also give rise to mistaken observations. Muscae volitantes or "flying gnats" are small solid particles that float about in the fluids of the eye and cast shadows on the retina. They often can be seen when you look up at the clear sky, or when you are reading. They move as your eyes move. It is sometimes possible also to see corpuscles or other objects that are circulating within the fluids in the ~~retina~~ of the eye.

Then, of course, everyone from time to time mistakes some more or less familiar object for another object. A probable explanation for many reports of unidentified aerial phenomena is that the object is really something quite familiar, such as an aircraft, a light, or a bird. The observer simply fails to identify it correctly. These errors arise chiefly as a result of inability to estimate speed and distance.

(2) <u>Mistaking Imaginary for Real Events.</u> This error of observation is usually made ~~only~~ by children, by individuals of low intelligence (people who are very suggestible), by people who see visions, or by the mentally ill. It usually is not difficult for an

expert to spot this type of person. Reports will be received by such persons especially at times when the radio and newspapers carry accounts of strange phenomena. Relatively few of the 212 investigations considered in this report are of this nature, probably because investigators interviewed only the more reliable type of witness.

(3) Deliberate Falsifications. It is always possible that some persons will give false reports. Circulation of false reports has been a standard psychological warfare technique from earliest times. This procedure might have some utility in wartime, but it hardly seems likely that it would be resorted to at this time. Probably, however, some individuals start false reports of "flying saucers" for the same reason that they turn in false fire alarms.

Some Consistent Points in the Reports of Unidentified Objects.

The following section summarizes some significant facts that come out of a tabulation of 212 reports of interrogations, by USAF Intelligence Officer, of some of the individuals who reported seeing unidentified flying objects. It is understood that these interrogations covered primarily persons that were judged to be reliable. Most of the 212 reports were made by pilots, non-flying officers, professional men, government employees, housewives and other supposedly dependable people.

1. Number of objects. About 79% of the people who reported on the number of objects seen said that they saw only one object.

2. Time the object remained in sight. About half of the persons specifying time in sight saw the object for 60 seconds or less.

3. Altitude and distance of the object. Of those who estimated the distance of the object, two-thirds judged it to be more than a mile away. Ninety percent also thought that it was more than 1,000 feet high.

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4. Speed. About half judged that the speed was less than 500 miles an hour. The other half of the judgments varied from 500 miles an hour all the way to "terrific", "tremendous", "inconceivable" and "blue blazes".

5. Background against which viewed. The great majority of observers saw the object against a clear day or night sky.

6. Time of day sighted. About two-thirds as many observations were reported at night as in the day. There are, of course, many more opportunities for observing things during the day. The most popular hours were from 12 noon to 5:00 P.M. and from 7:00 P.M. to 11:00 P.M. at night. Very few (6 only) observations were made from 5:00 to 7:00 P.M., the usual hours of sunset.

7. Color. Observers almost universally reported seeing a light-colored object. Thirty observers reported "white" and ~~twenty-five~~ said "silver". Over 70 percent described glittering, shiny, ~~luminescent~~, mirror-like, flame-like or other very bright objects. Only six individuals said black or dark.

8. Shape. Over half described the object as either "round", "disc-shaped", "spherical" or "circular". Other descriptions were similar. Very few observers saw any distinctive shape.

9. Size. The majority of observers did not specify the objects' size. Of those who did over half said it was less than 10 feet in its largest dimension. Many compared it with a dime, a lamp, a dot, a weather ballon, a baseball, etc.

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Interpretation of the Common Points of All Reports

The words used by observers to describe the appearances of the unidentified objects fall into a surprisingly uniform pattern. The objects were usually reported as being far away, small, bright and without a distinctive shape. They were usually seen against a clear sk y

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and were frequently seen for less than a minute.

First of all, it is obvious that it would usually be impossible for observers to make reliable estimates of the speed, distance, or size of such stimulus objects. It is not possible to estimate accurately the distance of small bright objects viewed against a clear sky, unless the object is identified first. If you know beforehand that an object is a weather balloon, an F-80, or a dirigible you can estimate its speed and distance with some degree of accuracy. In such situations distance is judged on the basis of known size, and speed on the basis of an estimate of distance plus the angular change in position. It must be concluded, therefore, that most of the statements of speed, distance, altitude and size are entirely unreliable and should be disregarded. This is doubly true of observations made at night. The objects seen may actually have been at very great distances, or they may have been relatively close by. In the latter case, of course, they could also have been quite small.

Secondly, it is probable that individuals who saw objects in daylight were in many cases observing either the reflection of the sun on a shiny surface or else looking directly at a light source of high intensity. Aircraft themselves, when viewed against a clear sky, are seen as dark objects against a lighter background unless they are reflecting the sun's rays directly. This fact was recognized during the recent war by camouflage experts who placed bright lights on the leading edges of the wings of aircraft on anti-submarine patrol in order to conceal them from the eyes of submarine lookouts. If observers, during daylight hours, were actually seeing lights, or reflections of the sun, this would account in large measure for their inability to identify the objects. On the other hand, if they were actually seeing enemy missiles, for example, the majority of reports

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of daylight sightings should have been of dark objects.. It is possible, of course, that they may have thought the objects were bright because they expected all aerial objects to be bright.

On the basis of the evidence thus far considered, the best guess as to the nature of a visual stimulus that would elicit reports of unidentified flying objects is that in the daytime it would be the reflection of the sun from an aircraft, a wind-blown object, etc., and at night some direct light source, such as an engine exhaust, the light on a weather balloon, a running light on an aircraft, a meteor, etc., or lights from the ground or the moon reflected back by birds or other objects in the air.

Discussion of Several Specific Reports

Discussion of a few specific reports will serve to illustrate some of the points brought up earlier, particularly some of the factors that make observations of aerial phenomena inaccurate.

Incidents No. 81 and 163.

In one case (Investigation No. 81) a civilian employee at Hickam Field at 0900 observed what looked like a balloon with a bright object suspended below it. It was estimated to be at about 6,000 ft. The bright object appeared to reflect the sun's rays at times. After a few minutes he looked away and then could not find the object again.

In another case (No. 163) a reserve officer at Van Nuys, California, about an hour before dark saw an object that looked somewhat like a weather balloon at about 2000 ft. He kept it in sight for about an hour. He later concluded that it was at a great height. At first it had the color of a fluorescent electric light but became orange as the sun went down and then rather suddenly became invisible.

Both of these objects could well have been just what they appeared to resemble most—balloons. The sun was low in the sky in both cases.

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Reflection of the sun's rays may have given an unusual appearance to the object. The second case illustrates the uncertainty of judgments of height or distance. The object looked near, but when it remained in view for an hour the observer decided that it must be very far away. Actually he probably had nothing on which to base an accurate estimate. of distance.

Incidents 61 and 61a.

Two couples saw approximately 12 objects flying in formation at what they judged to be 2000 or 3000 feet altitude over Logan, Utah at 22:30. They were judged to be about the size of pigeons and looked white. All four observers agreed that these objects looked and acted somewhat like birds but all thought they were not birds because they appeared to travel much faster than birds.

As we have seen, it is not possible to judge speed accurately under the conditions of these observations, i.e., when looking at objects of unknown size and distance against a night sky. The objects may actually have been a flock of white birds, flying at a relatively low altitude and reflecting the lights of the city.

Incidents 30, 30b, 30c, and 48, 48a, 48b, 48c, 48d.

During the same space of time (about half an hour) on the night of 7 January 1948 observers at Lockbourne Air Force Base, observers at Clinton County AFB and the pilot of an aircraft flying from Dayton to Washington reported an unidentified object in the sky. All reports agreed as to the color and general appearance of the object, and as to the fact that its light at times was visible through a light overcast. All agreed also that it was seen to the southwest. However, persons at all three locations judged the object to be only a few miles away. To all of them it looked motionless at times, then appeared to gain and lose elevation. A very similar object was seen by numerous

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28 April 1949

persons at Fort Knox and other towns in Kentucky a few hours earlier. All saw it in the southwest and many thought it was only a few miles away. The Commanding Officer at Goodman Field observed it for 1 1/2 hours, (beginning at 1445). During this time it seemingly remained stationary. It was "chased" by four National Guard pilots, one of whom crashed after having been up to 20,000 feet. It was also reported by persons in Lexington, Madisonville, and Elizabethtown.

The significant fact that emerges from these reports again is the inability to estimate distance. It appears possible that persons over parts of Kentucky and Ohio may have been seeing the same astronomical phenomena which was a great many miles away. Nevertheless each believed it to be relatively near his own location.

Incident No. 172.

A National Guard Pilot returning to Fargo, North Dakota, in a F-51 at approximately 2100 hours saw a small light in the air below him. He was then in the traffic pattern. He dived on the light. The light gained altitude. The pilot "chased" it up to 14,000 feet, making various passes at it and attempts to ram it as he climbed. He finally stalled out.

Several inferences can be drawn from the several reports about this incident. In the first place, when it is night, and a pilot is turning so steeply, and going such violent acrobatics, that he sometimes blacks out, as was the case here, it would be very difficult if not impossible to judge at the same time what another object was doing. In the second place, if the pilot kept his eyes intently on the object, as also was the case here, he would have great difficulty in knowing and reporting later what he himself was doing. The situation is very conducive to loss of orientation. In other words, it is impossible to infer from the pilot's re[illegible] whether the light pursued by him was

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maneuvering or not maneuvering. It is quite possible that it was simply climbing steeply on a relatively straight course, such as would be taken by a lighted weather balloon.

As a matter of fact, a lighted weather balloon was released by the Fargo Weather Station within 10 minutes of the time the light was first sighted by the F-51 pilot. It is the opinion of the writer that this lighted baloon easily could have accounted for all of the pilot's observations. (It should be noted that the standard 30 inch and 65 inch weather balloons have a vertical speed of about 600 and 1100 ft./min. respectively.)

<u>General Discussion and Summary</u>

In the preceding section the hypothesis has been advanced that most reports of unidentified flying objects have been the result of persons failing to identify familiar phenomena, such as reflections from bright surfaces in the day or lights in a night sky. It is believed that this explanation will account for many of the reports. However, some reports undoubtedly have other explanation.

<u>Vertigo.</u> The term vertigo covers a large group of miscellaneous phenomena including air sickness, disbelief in one's instruments, and partial loss of orientation. The conditions under which some of the observations of flying objects were made were such that they could have produced loss of orientation on the part of an observer. This is especially true for those experiences occurring at night and those in which attempts were made to "chase" the object. Movement is always relative. If the only outside reference is a point of light, and both the observer and the object observed are moving, it would be practically impossible under certain conditions to tell which was moving and which was not, or to separate out the two motions. It is hard enough

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to fly a good pursuit curve on another aircraft in good daylight, for example, much less to close on a solitary light at night. The difficulty is due chiefly to the inability to judge distance or speed of a point source of light.

__Suggestion.__ Suggestion works in various ways. Sensational radio and newspaper reports lead a few people to imagine they are seeing things they are not seeing. The effect on most people is to dampen their critical judgment. Under such conditions we are more likely to overlook certain factors, and find it easier to accept the suggested explanation uncritically. The expected result would be to make the reports of most observers slightly less accurate than if they had never heard reports of others seeing "flying saucers". Particularly when the stimulus object is fuzzy or ill-defined, persons tend to see it as resembling whatever is suggested to them. Carmichael et. al., for example (1932) showed individuals simple designs and gave them the name of an object. When the individuals drew the design from memory, they drew it to resemble whatever the object was that had been suggested to them.

__Precedent.__ An historical precedent can be found for most errors of human observation. Although the writer has not tried to make an historical survey of reports of earlier unidentified aerial objects, he feels sure that there have been many such reports in years past, particularly during and after World War I.

__Small Wind-borne Objects.__ It is possible that some observers may have seen small objects carried aloft by strong winds, or objects dropped from aircraft. Bits of paper, small cartons, etc., may occationally be carried to a considerable height by strong winds. Aircraft may sometimes jettison small articles. It would be impossible to

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estimate the distance, size or speed of such objects, and it would be easy to fail to recognize them.

Conclusions

It is concluded by the writer that there are sufficient psychological explanations for the reports of unidentified flying objects to provide plausible explanations for reports not otherwise explainable. These errors in identifying real stimuli result chiefly from inability to estimate speed, distance and size.

Recommendations

The following recommendations are offered:

1. Test the ability of pilots to estimate the course of a small lighted balloon while doing aerobatics with it at night. It is suggested that several pilots try to fly pursuit curves and collision courses on such targets at night and report accurately their sensations. It would be desirable, but probably impossible, to keep them from knowing the nature of the light source.

2. In all future reports of unidentified objects specify the location of the object with reference to polar coordinates (direction and degrees above the horizon) rather than asking individuals to estimate distance. If possible, obtain an estimate of size in terms of the visual angle subtended by the object.

3. In all future investigations determine the angular position of the sun with respect to the unidentified object and the observer. Also determine the approximate time during which the object was in sight (this information was not available for more than half the reports).

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Guilford, J. P. Autokinesis and the streaming phenomena. American Journal of Psychology, 1929, 40, 401-417.

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APPENDIX H

U. S. Department of Commerce-Weather Bureau

Information on Ball Lightning

C O P Y

UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU
Washington 25

In Reply Please Address
CHIEF OF BUREAU
and Refer to
0-4.3

Dec. 16, 1948

Commanding General
Air Materiel Command
Attention: MCIAXO
Wright-Patterson Air Force Base
Dayton, Ohio

Dear Sir:

Your letter of October 20, 1948, addressed to the National Bureau of Standards and requesting information on the subject of "Ball Lightning" has been referred to this Bureau for reply.

Attached is a tabulation filling in as well as practicable the information called for by the outline presented in your letter. We shall be glad to be of further assistance in connection with this matter.

Very truly yours,

/s/ P. W. Reichelderfer
P. W. Reichelderfer
Chief of Bureau

Attachment

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UNITED STATES DEPARTMENT OF COMMERCE
WEATHER BUREAU

Report

Information on "Ball Lightning"

I. Origin

Various theories and suggestions have been proposed to explain ball lightning, most of them being without well-established physical foundation. There is still doubt in scientific circles regarding the origin of a number of reported cases of ball lightning.

Briefly, the explanations of the origin of ball lightning may be broken down as follows:

(1) Brush discharge (St. Elmo's fire).

(May be stationary over sharp-pointed objects, or moving along or near the surface of wires, roofs, rocks, etc., especially on mountains. Conditions most favorable for brush discharge occur during thunderstorms, but the phenomenon may occur even during clear, dry, dusty weather. When a lightning stroke is approaching an object, the brush discharge becomes especially intense.)

(2) Intensely ionized, incandescent volume of air forming end of lightning stroke and lasting for short interval of time.
(This would occur mainly during thunderstorms following the passage of a lightning stroke. At the ground end, the terminal flash is intense, and vapors, smoke or molten material from objects fused at points struck may enhance and extend the duration of incandescence. After-image formed on the retinas of the eyes of a person looking at the brilliant flash at the point of discharge may give spurious effects.)

(3) Brush discharge in air containing high concentration of dust or other aerosols, during thunderstorms.
(If this occurs, it probably is associated with the path taken by a real lightning stroke, and presumably involves corona discharges from suspended particles and possibly combustion in some cases.)

(4) Jumping of gap by lightning indoors.
(When lightning strikes a house, lightning streamers may jump gaps such as between pipes within the house, thus causing a bright flash of limited extent. After-image is generally formed on the retina and movements of eye produce apparent movements of the illuminated region.)

(5) A cloud-to-ground lightning stroke with an associate, horizontally-directed, moving potential wave may possibly produce a transient horizontal potential gradient sufficiently intense to initiate electrical discharges.
(Such discharges would involve luminous darts moving at high speed and may move over irregular trajectories, producing, in some cases at least, more-or-less horizontally directed, sinuous, ribbon-like or tubular paths. If there is a heavy concentration of electrical charges near the earth beneath the thunderstorm the triggering of a discharge by the transient potential gradient may yield horizontal lightning streamers having a relatively slow propagation rate and long duration.)

(6) A lightning discharge that strikes and runs along a conductor such as power or telephone lines and flashes-over or jumps the gaps at breaks produces a brilliant illumination at the gaps that may be mistaken for ball lightning.

(7) A piece of wire with attached light object that is carried aloft by the gusty winds and turbulence attending a thunderstorm or tornado may serve to facilitate conduction of lightning currents and yield streamers at its ends during discharges.

(8) Spurious cases.

(a) After-image (persistence of vision)

(b) Will-o'-the Wisp

(c) Meteorites

(d) Reflections of lightning observed on highly polished objects, such as door knobs.

(e) Falling molten metal

(f) Lightning channel seen on end.

II. Appearance

(a) Forms

Spherical, roughly globular, egg-shaped, or pear-shaped; many times with projecting streamers; or flame-like irregular "masses of light." Appearance of outer boundary is generally hazy or ill-defined. Photographs of the phenomenon may show one or several sinuous, tubular propagation paths (trajectories taken by luminous darts), which may have associated with them broader luminous spaces of irregular configuration. (These latter spaces probably are regions where the sinuosities of path became involved and tortuous or are areas of major discharge where darts originated or terminated). Some paths show a beaded structure (alternate luminous and dark spaces).

(b) Color

Luminous in appearance, described in individual cases by different colors but mostly reported as deep red and often as glaring white. One scientist described the color in a certain case as similar to that he has noted in the laboratory on observing active nitrogen, or possibly slightly darker. Another observed one of yellow and still another of lavender or rose color. Others have reported some of blue appearance. The luminous mass is occasionally stated to be surrounded by a border, weakly but differently-colored than the main body.

(c) Degrees of Brilliance

Brilliance at most glaring white and incandescent. Minimum brilliance equal to that of feeble St. Elmo's Fire.

(d) Movement through Space

1. Possible directions.

   Generally downward, inclined or horizontal, in straight, curved, or tortuous paths. Mostly observed near the surface, but may originate in thunderclouds, and so take a trajectory from cloud to earth.

2. Maneuverability

   May appear stationary, or moving. Range of speed is zero to values of the order of 10^7 cm./sec. In the latter, extreme case, the luminous darts observed are probably of the same general nature as the lightning streamer, although the path taken may be very irregular and even show reversals in direction. In some cases, long sections of paths of such luminous darts may show slight curvature. Near the ground or in closed spaces a much smaller speed is often said to be observed, mostly about 1 - 2 meters/sec. The "ball of fire" may seem to move or float along in a room, or to roll along the floor. In a thunderstorm, as may be experienced on a mountain top, an observer has reported "seeing balls of fire roll along the rocks and drop from one to another." Intense St. Elmo's Fire on sharp objects beneath thunderstorms may fluctuate rapidly in size, intensity, and orientation, or show displacements from one point to another, hence the flame may appear to whirl and dance, or move. When a lightning flashover at a point produces an after-image on the observer's retina, movements of the eyes cause corresponding movements of the image which the untrained observer attributes to the movement of a luminous "ball of fire" or flame. Ball lightning observed by Jensen[1] in the wake of a lightning flash through dust-laden air during a thunderstorm "appeared as a shapeless mass of lavender color which seemed to float slowly downward." Jensen states: "The rose-colored mass seemed most brilliant near the ground and gave the impression of a gigantic pyrotechnic display. Two or three of the globular structures seemed to roll along a pair of 2300 volt power lines for 100 feet or more, then bounded down on the ground and disappeared with a loud report."

When a lightning streamer from a thundercloud terminates in the air, the leader stroke is sometimes so faintly luminous in portions that only a segment of the path is observed. This may conceivably give the impression of elongated "ball lightning," but is a natural cloud-air lightning stroke.

3. Nearby Air or other Craft

There have been numerous cases of aircraft struck by lightning. When the aircraft is all-metallic, it serves as a Faraday cage, and provides electrical protection

1. Jensen, J. C. Physics, vol. 4, p. 372 (1933).

to the crew and passengers. Just preceding the onset of a lightning stroke to an aircraft, pilots have reported observing a streamer of corona discharge build up on the nose, propellers or other extremity of the craft[1]. The movement of the streamer accompanies that of the aircraft and depends on the passage of a lightning stroke nearly or through the aircraft. Corona discharges on sharply convex surfaces of aircraft have also been observed during flight between masses of clouds strongly charged with electrical charges of opposite sign (positive and negative). Autogenous charging of the aircraft by tribo-electric and other effects during flight through snow or other precipitation particles intensifies the corona discharges. These are of the same nature as St. Elmo's Fire.

St. Elmo's Fire has been observed numerous times on the mastheads of ships and generally moves with them during passage beneath thunderclouds or other meteorological conditions where intense electrical potential gradients exist.

(e) Effect on Surrounding Atmosphere

1. Clouds

Lightning of any kind can occur in clouds only if the dielectric properties of the air are broken down when the sparking potential gradient is reached. In clear air this amounts to about 30,000 volts per cm. at sea level and about 21,000 volts per cm. at 10,000 ft. altitude. In clouds, or in the presence of precipitation particles the sparking potential gradient is less, depending on the size of the particles. For example, in the presence of raindrops 1/8 inch in diameter it is about 10,000 volts/cm.

As shown by Macky[2], droplets of water suspended in an electrical field sufficiently intense to induce breakdown will display sparking-over phenomena and will

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1. Harrison, L. P., "Lightning Discharges to Aircraft and Associated Meteorological Conditions," N.A.C.A. Technical Note 1001, (1946).
2. Macky, W. A., Proc. Roy. Soc. London, Ser. A, vol. 133, pp. 565-567, (1931).

become deformed. Under very strong fields, the droplets become drawn out into filaments and disrupt with attendant electrical discharges along their surfaces or through them.

It is probable that these phenomena occur along the channel of a lightning stroke through a cloud, and that some evaporation and disruptive breakdown of droplets occur in consequence of the intense heat and flow of electrical charges. These major effects on cloud or precipitation particles are believed to be confined to the lightning channel, although minor effects such as glow or brush discharges from particles in other portions of the cloud possibly occur in connection with the development of lightning strokes. These discharges from countless particles may yield a general illumination within the cloud under strong electrical field conditions, especially during propagation of lightning strokes.

Effects of "ball lightning" on clouds are unknown. Since "ball lightning," if real, is presumably less severe than an ordinary lightning stroke or at most is probably a dart streamer of such a stroke, we may assume that the effects of "ball lightning" on clouds are not more severe than those outlined above in connection with lightning.

2. Increased Ionization

The formation of corona discharge at any point leads to a considerable increase in ionization of the surrounding air. Any case of so-called "ball lightning" which is actually a corona discharge will have a similar effect.

Ordinary lightning strokes distribute heavy concentrations of electrons and ions or charged nuclei along and near their channels during the passage of the stepped leader or dart leader. These particles form a space charge surrounding the channel. After the leader reaches the earth, the return stroke occurs from earth to cloud. When this develops, the space charge tends to migrate rapidly to the channel, producing a rush of charges within it. The flow of these charges in the channel yields the brilliant, return lightning stroke. Within the channel ionization is exceeding heavy.

"Ball lightning" associated with a true lightning stroke will probably involve a flow of space charges to its channel and so leads to a diminution of space charge from the environment of the path but an immediate increase of ionization along its path. Following the passage of the phenomenon, ionization will decay by recombination.

3. Nearby Air or Other Craft

All metallic aircraft which are struck by true lightning generally have scorch marks, pits, or holes burned through the skin. The holes rarely exceed one inch in diameter. (See N.A.C.A. Technical Note 1001). Portions of non-metallic material in contact with the area struck may be burnt or explosively separated from the metal to which the material is attached. When radio antennae are struck or the lightning arrester does not function as desired, damage to radio equipment often occurs.

Temporary blinding of pilots looking directly at the flash due to the stroke to some exterior portion of the aircraft such as the nose of the fuselage may introduce some hazard. As a rule the temporary blinding is effective from about 10 seconds to a larger fraction of a minute, but in one extreme case a copilot was reported to have been temporarily blinded for about 8 minutes. Several cases of temporary blinding of about 3 minutes have been reported.

The Weather Bureau has not received any reports of accidents in which an airplane was said to have suffered contact with "ball lightning." Judging by the phenomenon called by that name and experienced at the surface, the aircraft damage to be expected by such contact would probably be less severe than that caused by a typical genuine lightning stroke. That type of so-called "ball lightning" which is actually an intense corona discharge would not cause any mechanical damage to non-inflammable exposed materials, but would hamper radio communications by producing static similar to the kind termed "precipitation static."

A real lightning stroke to a non-metallic object on the ground often causes an explosive disruptive effect on the object and will cause burning of inflammable materials.

Contact of so-called "ball lightning" may have physical effects on exposed persons varying from negligible to fatal. In the cases of fatalities resulting from this cause, it is believed that genuine lightning was involved. Physical effects of electrical origin on persons enclosed in all-metallic aircraft are negligible, owing to the Faraday cage protection afforded by the conducting skin. However, a slight electrical shock may be experienced by a crew member aboard an aircraft if he is making good contact at two well separated points during passage of the steep wavefront of potential through the area of contact at the time of a real lightning stroke.

(f) Accompanying Phenomena

1. Sound

The origination and dissipation of "ball lightning" at the surface are often attended by a sharp report, but not invariably. Very frequently the beginning or end, respectively, of "ball lightning" is accompanied by a positively identified stroke of streak lightning to or very nearly to the point of observation. The thunder produced by such a stroke will naturally be considered by many observers to have been associated with the "ball lightning." "Ball lightning" which is in the form of a corona discharge makes very little sound, since the current carried is very low and the explosive heating effects on the air negligible. Lightning of the continuing-current type, with low-wavefront, will not produce intense sounds, and this is to be more or less expected, also, of isolated luminous dart streamers traversing the channels of preceding or succeeding lightning strokes. Such streamers have been included in the category of "ball lightning."

2. Chemical Effects

The odor of ozone in connection with "ball lightning" has been reported by some observers. This is to be expected in cases where the phenomenon is a brush discharge which produces ozone in air. When actual streak lightning is involved, the formation of oxides of nitrogen and ozone is a normal occurrence.

3. Thermal Effects

Fires have been caused in combustible material, such as straw, by discharges reported to have been "ball lightning."

4. Electrical Effects

"Ball lightning" will certainly be accompanied by radio static in some form. Electrical shock to persons is possible when the phenomenon stems from streak lightning. Disruptive mechanical effects on non-conductors especially if containing moisture, or crushing effects on hollow conducting tubes may occur in cases where actual steep wave-front, lightning currents pass through the objects.

5. Optical Appearances

Some of the cases of "ball lightning" observed have displayed excrescences of the appearance of little flames emanating from the main body of the luminous mass, or luminous streamers have developed from it and propagated slant-wise toward the ground. In rare instances, it has been reported that the luminous body may break up into a number of smaller balls which may appear to fall towards the earth like a rain of sparks. It has even been reported that the ball has suddenly ejected a whole bundle of many luminous, radiating streamers toward the earth, and then disappeared.

Jensen[1] has quoted the following report of electrical discharges appearing in a violent storm; "A tornado which occurred on the evening of July 9, 1932, near Rock Rapids, Iowa, gave evidence of a closely related type of luminous display according to the report of Mr. George Raveling, U. S. Weather Bureau observer. From the sides of the boiling, dust-laden cloud a fiery stream poured out like water through a sieve, breaking into spheres of irregular shape as they descended. No streak lightning of the usual type was observed and no noise attended the fire-balls other than the usual roar of the storm."

(g) Possible Objects to Which Attracted

Lightning strokes are more likely to hit at or near the top of high, pointed objects, than on the surfaces of low objects with flat or concave exteriors. If the tips of the high objects are grounded via conductors such as wires or metal pipes, they will tend to show a higher frequency to strokes than ungrounded objects. This is especially true if, in the former case, the

1. Jensen, J. C., Physics, vol. 4, p. 374 (1933).

ground is well moistened or possesses an extensive network of conducting elements (water pipes, telephone and electric cables, etc.)

It follows that the lightning flash will be observed more frequently at these relatively-high points than elsewhere, and hence probably that "ball lightning" will appear to develop quite commonly at such points.

Brush discharges tend to form at sharply convex extremities of objects, and align themselves in the direction of the potential gradient. Well-grounded and conducting objects would generally receive preference. These considerations apply to cases which were classified by the layman as "ball lightning" but actually were cases of St. Elmo's Fire (bright glow or brush discharges).

There have been reports by observers of "ball lightning" to the effect that the phenomenon appeared to float through a room or other space for a brief interval of time without making contact with or being attracted by objects. Holzer and Workman[1] have published a reproduction of moving film camera photographs of unusual discharges during thunderstorms. In the case of the phenomenon observed at Santa Fe, New Mexico (elevation 7000 feet) on the night of September 3, 1936, these authors state: "The cameras were mounted rigidly on a bench in a portable laboratory. The discharge was probably about 100 feet from the cameras, although the exact distance is not known since no thunder addociated with this flash could be distinguished from the general background of thunder. The discharge occurred within less than one-thousandth of a second after an intense cloud ground stroke not shown on this portion of the film. Analysis of the photographs indicates that the discharge consisted of at least four luminous darts moving with a projected velocity of the order of 10^7 cm/sec. The most notable features of this discharge are: (1) its irregularity of path and rapid reversals in direction, (2) its proximity to ground objects with no apparent contact with the ground, (3) the beaded nature of the path, and (4) the progress of the discharge in two directions from a single point."

Note should be made of the fact that the luminous darts did not appear to be attracted to available ground objects even though they were in the vicinity of the ground. On this basis it cannot be stated whether there are any definite objects to which all cases of "ball lightning" would be attracted. We should think that sharp-pointed, grounded objects are most likely to attract "ball lightning."

1. Holzer, R. E., and Workman, E. J., Jour. of Applied Physics, vol. 10, p. 659 (1939).

(b) Methods of Terminal Dissipation

As a rule so-called "ball lightning" of the variety which we judge to be intense brush discharge dissipates when the potential gradient diminishes to a value below the critical one for maintenance of the discharge. This generally occurs following lightning strokes which largely discharge the heavy concentrations of electric charges of opposite sign in the overlying thundercloud.

"Ball lightning" which appears to form at sharp-pointed objects as a lightning stroke approaches disappears when (a) the main lightning currents cease flowing just after contact of the stroke or (b) the space charge around the lightning channel is largely collected into the channel and transported to earth or cloud.

"Ball lightning" which appears to be a luminous dart like a meteorite rapidly falling (or rising) along the path of an immediately preceding or succeeding lightning stroke disappears into the earth (or cloud).

"Ball lightning" in the form of a luminous ball apparently moving through a space or rolling along the ground dissipates eventually, perhaps on making contact with some object. Some observers have stated that the ball collapses with a noise resembling that of a big firecracker, leaving an odor of ozone. It seems probable that in these cases also the dissipation takes place when the potential gradient has diminished below the critical value for maintenance of the discharge, simultaneously with the occurrence of a genuine lightning stroke to the area involved.

As indicated previously, reports have also been given that the main body of the "ball lightning" has appeared to have broken up into a number of smaller "balls" which have fallen to earth, or to have emitted small streaks, like lightning, projected towards the earth, and thus dissipated.

A sound of thunder, of greater or lesser intensity, may accompany the dissipation. It is not possible to be certain that the sound is always intimately connected with the phenomenon, for it may have been the thunder associated with a nearby lightning stroke.

III. Recommended Material for Questionnaire

1. Name and address of person who observed phenomenon

2. Age, education and employment of person (Specify especially training, if any, in scientific fields such as physics, engineering, etc.)

3. Name, address and educational qualifications of person who prepared questionnaire

4. Date and time of occurrence

5. Geographic location

6. Elevation

7. Character of observation point and surroundings (State whether inside or outside; kind of structure, if any; neighboring structures or ground objects; and terrain)

8. Illumination available (natural and artificial)

9. Weather conditions (as thunderstorm, rain, overcast)

10. State whether genuine streak lightning was observed (a) before, (b) after, the "ball lightning"; and indicate time interval between phenomena

11. Indicate direction and apparent distance of such streak lightning; also objects believed to have been struck by it

12. State whether glow or brush discharges were observed (a) before, (b) after, the "ball lightning"; and indicate time interval between phenomena

13. Indicate locations at which glow or brush discharges were observed, and objects on which they appeared

14. Indicate brightness of discharge at points of occurrence referred to in (11) and (13)

15. Shape of ball lightning observed

16. Transparency of "ball" and general appearance of its exterior and periphery

17. Changes in its form

18. Indicate whether flames or streamers emerged from it, and describe them

19. Location, distance, and height of phenomenon when first observed

20. Apparent size of phenomenon

21. Rotation, if any, observed

22. Colors

23. Brightness

24. Smoke or vapors emitted (color, odor, form, etc.)

25. Odor (during and after occurrence of phenomenon)

26. Heating effects, if any

27. Physiological effects

28. Mechanical effects

29. Electrical or magnetic effects

30. Sounds accompanying original appearance and life-span of phenomenon

31. Path taken by "ball lightning," including height and location during its life span

32. Movements of observer during phenomenon (including movements of head and eyes, if possible)

33. Speed of motion of "ball lightning"

34. Duration of phenomenon and duration of period of observation

35. Indicate any special conditions observed to attend beginning of phenomenon

36. Indicate conditions observed at time of ending of phenomenon

37. Traces, if any, left after dissipation

38. Psychological effect on observers

39. Was sould like that of thunder heard at time of its disappearance? Describe its intensity and character