SA-376 File No. 1-0015

# CIVIL AERONAUTICS BOARD

# AIRCRAFT ACCIDENT REPORT

**ADOPTED.** February 25, 1965 **RELEASED.** March 3, 1965

PAN AMERICAN WORLD AIRWAYS, INC
BOEING 707-121, N709PA
NEAR ELKTON, MARYLAND
DECEMBER 8, 1963

## SYNOPSIS


A Pan American World Airways, Inc., Boeing 707-121, N709PA, Flight 214, crashed at 2059 e.s t., December 8, 1963, near Elkton, Maryland

Flight 214 was in a holding pattern awaiting an instrument approach to the Philadelphia International Airport when it was struck by lightning. Immediately thereafter, the aircraft was observed to be on fire. A large portion of the left wing separated in flight and the aircraft crashed in flames approximately ten nautical miles southwest of the New Castle, Delaware VOR. All persons aboard, 73 passengers and eight crew members, perished in the crash and the aircraft was destroyed.

The Board determines the probable cause of this accident was lightning-induced ignition of the fuel/air mixture in the No. 1 reserve fuel tank with resultant explosive disintegration of the left outer wing and loss of control.


Accident

Pan American Flight 214, a Boeing 707-121, N709PA, departed Friendship International Airport, Baltimore, Maryland, for Philadelphia, Pennsylvania, at 2024 1/ December 8, 1963. The aircraft, with 73 passengers and a crew of eight, was on an Instrument Flight Rules (IFR) clearance. Flight 214 reported over the New Castle, Delaware VOR at 2042 and was instructed to hold at 5,000 feet, west of the VOR. At 2058 a "MAYDAY" 2/ transmission was heard from the flight. Shortly thereafter, the pilot of another aircraft broadcasted that "Clipper 214 is going down in flames "

Flight 214 crashed two miles east of Elkton, Maryland, at 2059. All persons aboard the aircraft were killed instantly. The aircraft was destroyed by explosion, impact, and fire.

1/ All times herein are eastern standard based on the 24-hour clock.

2/ A radio call signifying an aircraft in distress.

Investigation

On the morning of December 8, 1963, N709PA departed Philadelphia, Pennsylvania, as Pan American Flight 213 and proceeded to San Juan, Puerto Rico, with an en route stop at Baltimore, Maryland. The aircraft arrived at San Juan with 25,500 pounds of fuel 3/ remaining aboard. The aircraft was fueled with Type B to a total of 78,000 pounds. The resultant fuel load was a mixture of Type A and Type B distributed as follows. Nos. 1 and 4 main and reserve tanks 69 percent Type B; Nos. 2 and 3 tanks 63 5 percent Type B, center tank 100 percent Type B.

Prior to departure from San Juan the captain of Flight 214 was briefed on the weather along his intended route to Philadelphia. This briefing included a discussion of SIGMET No. 3 4/ relative to possible thunderstorm activity, and turbulence. The times of frontal passage at certain east coast cities including Baltimore and Philadelphia were also discussed. The captain was also provided with a "flight folder" which contained the required weather documents

N709PA left San Juan as Pan American Flight 214 at 1610 and arrived at Baltimore at 1935. No maintenance discrepancies were reported by the crew at Baltimore. A visual inspection of the aircraft, including examination for fuel leaks, was performed by a Pan American mechanic, while the aircraft was being refueled, and no discrepancies were noted. 27,400 pounds of Type A were added at Baltimore resulting in the following quantities and mixtures Nos. 1 and 4 reserve tanks an estimated 1.81 gallons of residual fuel, approximately 69 percent Type B, Nos. 1 and 4 main tanks 12,000 pounds of fuel each, 31 percent Type B; center tank, estimated 15.05 gallons residual fuel, 100 percent Type B. Fuel temperatures were estimated to be 42°F in the reserve tanks and 46°F in the mains. After the accident fuel samples were taken from the supply sources at Idelwild, Baltimore, and San Juan. Analysis of these samples revealed no discrepancies.

At Baltimore a Pan American operations representative talked to the captain about the weather between Baltimore and Philadelphia. He provided the captain with copies of the 1900 east coast weather sequence reports. The operations representative told the captain that the front passed Baltimore ".. a little while ago ..." and would be in Philadelphia "... about 0125Z (2025)."

Flight 214 departed Baltimore at 2024 cleared IFR to the Port Herman Intersection via Victor 44 (airway), Victor 433, at 4,000 feet, to expect further clearance after Port Herman via Victor 433 to the New Castle VOR thence direct to Philadelphia.

After takeoff, Baltimore Departure Control provided radar vectors to Victor 44 where air traffic "control" was transferred to New Castle Approach Control. The Baltimore radar monitoring of the departure revealed neither unusual flight progress

3/ Type A is a kerosene type turbine fuel with a flash point of 110° - 150°F Type B is a wide-cut gasoline type turbine fuel with an unspecified flash point and a maximum Reid vapor pressure of 3 p.s.i.

4/ A meteorological message designed primarily for aircraft in flight warning of weather conditions potentially hazardous to transport category and other types of aircraft. SIGMET No. 3 was issued by the USWB office, Washington National Airport.

not significant weather Radar service was terminated eight miles west of the Rock Hall Intersection at 2031.

Communication was established between Flight 214 and New Castle Approach Control, which had no radar. The flight was cleared to climb to 5,000 feet and recleared to the New Castle VOR. Flight 214 reported over the New Castle VOR at 2042, 5,000 feet and control was then transferred to Philadelphia Approach Control which provided the crew with the following·

> "... Philadelphia weather, now, seven hundred scattered, measured eight hundred broken, one thousand overcast, six miles (visibility) with rain shower, altimeter two nine four five, the surface wind is two hundred and eighty degrees at twenty (knots) with gusts to thirty (knots). I've got five aircraft, have elected to hold until this ... extreme winds have passed, ... do you wish to be cleared for an approach or would you like to hold until the squall line . . passes Philadelphia, over?"

The crew advised Philadelphia they would hold and were instructed to hold west of New Castle VOR on the 270 radial and given an expected approach clearance time of 2110. The crew requested and received permission to use two minute legs in the holding pattern. At 2050 45 the crew advised Philadelphia they were ready to start an approach. They were told to continue to hold and they would be cleared as soon as possible. The crew acknowledged with "Roger, no hurry, just wanted you to know that .. we'll accept a clearance." Approximately eight minutes later, at 2058:56 the following transmission was heard on the Philadelphia Approach Control frequency 124 6 "MAYDAY MAYDAY MAYDAY" 5/ Clipper 214 out of control. Here we go." Seconds later another transmission on the same frequency was heard "Clipper 214 is going down in flames." This latter transmission was made by the first officer of National Airlines Flight 16 (NAL 16). 6/ NAL 16 was in the same holding pattern as Flight 214 but 1,000 feet higher, and the first officer had seen the Pan American flight descending on fire.

The aircraft crashed at 2059 in open country east of Elkton, Maryland. Witnesses in the accident area described the weather as cloudy, with light rain falling, and lightning.

Turbulence, thunderstorms, and icing were included in all routine forecasts as well as SIGMETS for the area surrounding the accident site during the period Flight 214 was to be operating in that region.

The weather at Wilmington, Delaware, nine nautical miles east of the accident, was reported, at 2100, to be:

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5/ This portion of the recording is not entirely clear, but this represents the best interpretation possible due to the quality of the tape.

6/ NAL Flight 16 was a Douglas DC-8, N875C.

900 scattered, measured 4400 overcast, visiblity 8 miles, thunderstorm, light rain, temperature 44, dew point 43, wind west-southwest 10 knots, thunderstorm began at 2054, thunderstorm west, movement unknown, lightning in cloud, cloud to ground west-northwest - northwest.

The Wilmington 2000 report had indicated a frontal passage at 1931.

The weather in the holding pattern area as described by the first officer of Flight 16 was cloudy, with comparatively smooth air, and the ground lights were occasionally visible through breaks in the clouds. The crew of this flight observed a lightning strike on their aircraft while in the holding pattern. Later examination of the aircraft revealed evidence of lightning damage to the left wing tip and the empennage.

Of the 140 ground witnesses interviewed, 99 reported sighting an aircraft or flaming object in the sky. Seventy-two of these witnesses saw lightning and seven stated they saw the lightning strike the aircraft. Three other persons saw a ball of fire appear at the fork or one end of the lightning stroke. Seventy-two witnesses indicated that the ball of fire appeared concurrent with or immediately following the lightning stroke. Twenty-seven saw fire preceded by lightning with a very short interval before the fire was visible. Twenty-three witnesses observed an explosion in connection with the aircraft in flight after fire was observed. Thirty-eight mentioned an explosion at impact

Additionally, 28 witnesses saw objects fall from the aircraft in flight and 48 described various portions of the aircraft they observed to be in flames.

Nearly 600 pieces of wreckage were strewn outside the main impact crater in an area approximately four miles long and one mile wide. The long axis of this area was on a bearing of 255 degrees true from the easterly end through the impact crater near the westerly end. However, there were two distinct wreckage paths and three concentrations in this area.

One of these was a straight path about 1,500 feet wide and two miles long. It included the wreckage farthest from the main crater and consisted of nearly all pieces of the left outer wing panel, notable exceptions being the inboard portions of the outer panel rear spar and aileron. The bearing of this path was 250 degrees from its easterly end toward the impact crater, however, westerly extension of the path centerline passed approximately 2,500 feet south of the crater. The farthest piece of wreckage was approximately 19,600 feet and the nearest in this path 8,200 feet from the main impact crater. The density of these pieces varied from low to high progressing westerly along the 250-degree path.

Nearly all of the remaining scattered wreckage was strung out along a slightly curved path with a width of about 600 feet near the crater and a track of about 220 degrees to the crater in this area. Continuing easterly the path, except for a concentration of five pieces of wreckage about 4,500 feet east-northeast of the crater did not exceed 1,000 feet in width within 11,000 feet of the crater, at which point its track was about 255 degrees. At 16,000 feet from the crater it was approximately 2,200 feet wide and its tract was about 270 degrees. The most easterly piece of wreckage found along this path was approximately 17,400 feet from the crater. All pieces from there along this path to about 7,500 feet from the crater were very low in density, consisting of items such as Seat Occupied cards, cabin and air conditioning insulation, fragments of thin skin and stringers, etc. In an area about 1,600 feet long, centered approximately 4,300 feet from the impact crater, the wreckage consisted mainly of more dense pieces, such as center section fuel cell bags and backing strips, horizontal tail leading edge deicer strips, etc. Nearer to and still northeast of the crater there were numerous pieces of still denser wreckage, such as fragments of wing structure surrounding the center section fuel tank, air conditioning packs including the primary heat exchangers, the right horizontal stabilizer, etc. Within a radius of 360 feet from the main impact crater there were numerous pieces of dense wreckage including parts of the right wing and fuselage, right main landing gear, horizontal and vertical tail surfaces and the Nos. 2 and 3 engines and pods. The crater contained most of the fuselage and left inner wing wreckage, the left main gear and the nose gear.

In two small wreckage concentrations separate from the two previously mentioned paths, there were ten pieces, consisting of the Nos 1 and 4 engines, pylons and sections of their cowling The No. 1 engine and pylon assembly was approximately 1,440 feet on a bearing of 25 degrees and the No. 4 engine and pylon assembly approximately 1,925 feet on a bearing of 13 degrees from the impact crater. None of the other eight pieces was more than 165 feet from the corresponding engine.

Examination of the wreckage in conjunction with consideration of the wreckage distribution disclosed multiple indications of lightning damage, fire and disintegration in flight, which will be discussed in following paragraphs. However, the four powerplant pods in their entirety yielded only evidence of their having separated from the aircraft in flight due to excessive load factors, without engine failure or malfunction prior to separation.

A majority of the components of the various systems within N709PA were destroyed. The recovered portions of the hydraulic and electrical systems showed no evidence of operational distress or pre-impact failure. The fuel dump valves were determined to be in the "closed" position

A portion of the trailing edge of the left horizontal stabilizer was burned through and the paint was blistered along the entire upper and lower surfaces of the trailing edge. There was molten aluminum alloy splattered on the forward upper surface of the leading edge of the stabilizer which was determined to have been deposited in flight There was no evidence of fire damage on the right horizontal stabilizer. The left side of the vertical tail and aft fuselage were extensively scorched by exposure to fire in flight Numerous instances of in-flight fire were found on the recovered wreckage of the left inboard wing aft of the rear spar, although most of the external skin remained unidentified. In-flight fire damage was noted on the three steel tracks for the inboard flap and on the track at the inboard end of the outboard flap, the inner end of the outboard flap, fragments of the spoilers, dump chute components, cove lip doors, and fragments of the fore flaps.

The high frequency (HF) radio antenna had separated from the vertical tail section and exhibited numerous tiny pock marks which were dull in appearance.

The complete left wing tip, with portions of the left outer aileron and spar webs still attached, was found approximately 1.8 miles east-northeast of the main impact area Multiple lightning-strike marks were found on the left wing tip. There was an area of extensive damage on the top surface of the tip along the end rib, in and adjacent to the joint where the wing tip cap and the top wing skin were attached to the end rib. The damaged area extended from the trailing edge of the wing to a point about three feet eight inches from the leading edge, measured along the end rib Within this area there were numerous spots where the metal surface and rivet heads showed indications of melting, and associated dendritic patterns were visible on the wing surface. The largest single indication of lightning damage was an irregular shaped hole about $1\frac{1}{2}$ inches in diameter There was evidence of high heat in this area and fused metal was found around the hole. A smaller hole was burned adjacent to the outboard edge of the access cover over the fluxgate compass transmitter. Four rivet heads and small areas of metal adjacent to the rivets were burned off the top surface near the trailing edge of the wing tip. Numerous small lustrous craters were found in the wing tip cap ranging in diameter from 1/16 to 1/8 inch The depth of the craters ranged from 1/32 inch to complete perforation of the 1/16 inch thick wing tip skin. Evidence of fusion was found at the edges of two drilled holes in the wing tip cap and one of these holes had been enlarged by melting around the periphery. A darkened area was found on the end rib directly opposite one hole. The paint had been discolored by heat and there was localized charring of the paint A few small specks of fused metal were found on the paint. There was no evidence of pitting in the metal surface of the rib. The lightning damage nearest the fuel tank vent outlet in the bottom of the left wing was $11\frac{1}{2}$ inches from the edge of the vent outlet. Metallographic examination of several areas of lightning damage showed characteristic deposits of porous fused metal on the damaged surfaces and a distinct boundary between the affected and unaffected metal

The surge tank box[7/] was intact except for a 2.2 inch opening along the top extending from spar to spar. This opening encompassed the surge tank end of the vent passages from the fuel tanks. The ends of the fracture curled up and were moderately sooted. The bottom surge tank skin was curled downward at a fracture line along the tank end closure rib. Very slight outward bulging of the tank end rib was noted. The interior of the surge tank was heavily sooted on all sides and the sealant was burned inside.

The exterior of the wing fuel tank ram vent was moderately sooted inboard of the recess in the bottom skin The heaviest concentration of soot was below and aft of the tank vent screen There was evidence of heat in the inlet of the ram air vent scoop.

The wire bundle for the fluxgate compass transmitter showed signs of heat damage and charring of the insulation of one wire. This wire bundle was located in the surge tank ducting area. Disassembly of the surge tank ducting revealed light sooting on the interior wall and heavier sooting on the outside surface of the duct

A 27-inch section of the forward spar was bulged outward and the bottom spar cap was bulged downward There was slight sooting or discoloration on the reserve tank side of the spar and slight charring of the sealant at the juncture of the spar and the closure rib.

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7/ See attachment No 1, a schematic of the B-707 fuel system

The center tank 8/ bottom skin was separated in three pieces. Stiffeners and access doors were bowed outward. The largest section was bowed chordwise in an outward direction. There were no signs of fire damage

There was considerable ground-fire damage to the right inner wing.

The left outboard flap and spoiler skin were heavily sooted underneath caked mud. There was also soot under the mud on the inboard flap gear box area. The left inboard flaps showed evidence of fire damage. Measurement of the jackscrews indicated the left wing flaps were up The right outboard flap showed heavy fire damage and the bottom skin was burned away. These flaps were extended $1\frac{1}{2}$ to $2\frac{1}{2}$ degrees.

The ailerons and spoilers on both sides, except the outer half of the left outboard aileron, exhibited evidence of in-flight fire.

The aileron and rudder trim were neutral and the stabilizer was trimmed for 0.8 degrees noseup

The recovered wing and tail components were laid out in their respective positions for study of fire damage and the left wing tip and outboard sections were examined for evidence of lightning damage.

Electrical resistance measurements were taken across 21 fuel tank access plates. Readings obtained varied from 0.0000 ohms to 250,000 ohms. The higher readings were obtained where bondings had been broken.

A magnetic strength survey 9/ was made of the steel components of the left and right wings, center fuel tank, and the horizontal and vertical tail sections. The readings ranged from light to moderate with occasional areas of heavy magnetism.

Similar surveys were conducted on a USAF B-707-100 and a Pan American B-707-139 with 3,454 and 10,530 hours flight time, respectively. The results were generally similar except that the readings on the aft end screws on the fuel tank access plate of the left wing were higher on N709PA than on the two tested aircraft. This work was an attempt to delineate the path of the lightning-induced current through the wing strcuture. Despite the one variation in results of the three magnetic surveys, no information significant to the investigation was obtained.

The left outer wing and other parts were examined and analyzed by the National Bureau of Standards (NBS) in an effort to detect ignition points and confirm lightning damage. Special attention was given to the left wing tip and parts of the No. 1 reserve tank; the left fuel vent surge tank, the HF antenna probe cover, a piece of top skin from the right side of the center fuel tank with float valve attached, and the float valve from the right wing reserve tank.

Lightning discharges can be hazardous to aircraft fuel systems by possibly igniting the fuel vapor within the tanks. Direct strokes may penetrate the wall of

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8/ See attachment No. 1

9/ Magnetic strength surveys were made using a comparative Gaussmeter with a probe containing ferrous core coils, current amplifier, microammeter, and sensitivity adjustment. Movement of the probe across parts checked induced voltages into probe coils and results were shown in micro amperes the tank or cause internal sparking, either from the high resistive and/or inductive voltages developed across internal discontinuities, or from possibly high voltages induced in the fuel probe wiring In addition, flame can propagate through the vent system, from fuel vapors ignited at the vent outlet by direct strokes, streamering, or blast pressure waves, spark showers, and possible plasma penetration from direct strokes Accelerated studies have recently been completed into these hazards to provide technical data on their probable occurrence and control. These studies have also indicated the structural damage that would be caused by the different causes of ignition Neither blast wave compression nor induced streamer ignition would leave visible evidence of the cause of ignition. The various types of sparking could also cause ignition without leaving identifiable evidence but might leave such evidence if the sparking energy is sufficiently high to produce visible pitting or fusion of metal surfaces.

The lightning damage previously discussed was re-examined and confirmed. The detailed examination of surfaces, joints, rivets, screws, fittings, and fuel quantity probes for physical evidence of ignition-producing sparks where ignitable fuel/air mixtures may normally be present disclosed no identifiable evidence of electrical arcing. Thus, the actual mechanics of ignition of the left reserve tank contents was not determined

Metal splatters on the leading edge of the horizontal stabilizer were identified by spectrographic analysis as being formed from two different aluminum alloys. However, these alloys could not be identified since the chemical composition of the deposits did not conform to any alloy used in the airplane. The long axis of the deposits varied from 18 degrees inboard to 4 degrees outboard.

The aircraft records review indicated that N709PA was maintained in accordance with FAA and approved Pan American directives and procedures prior to the accident. These records revealed no history of fuel leaks, lightning strikes, or static discharges

The flight recorder tape was torn and crumpled but had little fire damage. Approximately 95 percent of the tape was reassembled and read out. The tape showed an elapsed time of approximately 32 minutes and 50 seconds from lift-off at Baltimore until impact with the ground. The record of the first 32 minutes of flight was normal and indicated no severe turbulence. 32:15 minutes after takeoff abnormal excursions appear The tape shows that the aircraft stayed at 5,000 feet for approximately 15 seconds after the beginning of the unusual excursions and then descended rapidly to ground level with little change in heading. The flight recorder tape of NAL 16 10/ showed no major differences between the traces of the two aircraft while they were in the holding pattern, insofar as evidence of turbulence is concerned.

The bodies of all persons aboard the aircraft were recovered and identified. Toxicological examination of the flight crew showed no evidence of alcohol or elevated carbon monoxide levels. Carbon monoxide tests of passengers also indicated no elevated levels The flight crew was physically qualified for flight according to FAA and Pan American records.

The flammability limits 11/ of a mixture of Type A and Type B fall somewhere

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10/ See footnote 6, supra.

11/ Limits of a fuel/air mixture that will allow combustion to occur. Below the lower limit the mixture is too lean to burn and above the higher limit the mixture is too rich to burn.

between the limits of either fuel examined separately. These limits vary according to the temperature and pressure. Flammability is also affected by misting or foaming of the fuel. Expert testimony at the hearing indicated that the fuel vapors in the air spaces of the tanks were well within the flammable range at the time of the accident.

Pan American World Airways conducted a flight test in a Boeing 707 to determine if fuel would discharge through the tank vent system ram air inlet. 12/ There was n visible discharge of fuel at any time during the test. There was evidence that fuel entered the vent system, collected in the surge tanks, and returned to the proper fuel tanks.

To clarify the subject of lightning, a U. S Weather Bureau witness was called to testify at the hearing and various technical reports were reviewed. These sources indicate that a lightning stroke begins when the air's resistance to the passage of electricity breaks down. At that time a faintly luminous stepped leader advances toward an area of opposite potential, the earth in the case of cloud to ground lightning. The difference in electrical potential between a cloud and the ground may be in the order of ten to one hundred million volts and discharge current may exceed 100,000 amperes with 10,000 amperes per micro-second 13/ rate of current rise.

The stepped leader advances toward the ground in a series of discrete branching movements, forming an ionized path down from the cloud. As a branch of the stepped leader is approaching the ground, the intensified electric field causes an upward moving streamer to form at a ground projection and advance toward the stepped leader As the oppositely charged leaders meet, completing the ionized channel, an avalanche of electron flow follows, discharging the cloud to the ground. This entire sequence is accomplished in approximately one millisecond. 14/ Additional charge cells in the cloud may then successively discharge through this main ionized channel as a single flickering flash which may last as long as one second. The electron flow suddenly heats the ionized channel to about 15,000°C , expanding the air supersonically outward with a thunderclap. The discharge can also occur between oppositely charged regions within a cloud, or in different clouds.

If the stepped leader of a stroke approaches a flying aircraft, the intense electric field induces streamers from the extremities of the aircraft out toward the approaching stroke. The stepped leader contacts one of these aircraft streamers completing the ionized channel to the aircraft and raising the potential of the aircraft to the order of 100 megavolts. 15/ This high potential produces streamers from all the extremities and high gradient points of the aircraft. These streamers can have sufficient energy to ignite fuel vapors. Meanwhile, the stroke leader continues on from the aircraft to another cloud or to the ground to complete the ionized channel for the electron avalanche.

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12/ The test conditions were: Fuel vent shutoff float valves removed from Nos 3 and 4 main tanks and float valves in the Nos. 1 and 2 main tanks intact; 12,000 pounds of fuel in tanks 1, 2, 3, and 4 main and with the reserve and outer tanks empty; flight conditions simulating moderate to rough air turbulence with skidding two minutes turns.

13/ A micro second is one millionth of a second.

14/ One thousandth of a second.

15/ Megavolt - equals one million volts.

Statistics indicate that the majority of lightning strikes to aircraft occur at ambient temperatures near the freezing level This correlates with thunderstorm electrification theories that charge separation occurs about the freezing level. N709PA was at or near the freezing level just prior to the accident.

ANALYSIS

The flight crew of N709PA was properly certificated and qualified for this flight. The flight was properly dispatched and cleared, and conformed to the air traffic control rules. The history of this aircraft reveals no item that stands in causal relationship with the accident

No evidence of any flight crew incapacitation, prior to impact, was found.

Air carrier aircraft operated into and out of Philadelphia immediately befor and after the accident. There were scattered thunderstorms and areas of severe turbulence in the Philadelphia area. However, the turbulence in the area where N709PA was operating was light to moderate and was not of the strength normally associated with a loss of control or structural failure. Even though the aircraf was operating in precipitation at or near the freezing level, icing is not consid a factor.

The weather documentation and briefing furnished the crew at San Juan was sa isfactory. The weather service provided the crew at Baltimore was not complete, ever, all the weather data available indicated that the cold front would be past Philadelphia and the weather would be improving upon their arrival. By definitio lightning is always present in thunderstorms. At the time and place of the accid a thunderstorm was present and lightning was observed and scattered thunderstorms were forecast for the area.

The record indicates that the flight was normal until 32:15 minutes after ta off from Baltimore. The aberrations appearing in the traces of N709PA's readout 32 15 after takeoff indicates the time of the explosion in the left wing. The pi was able to maintain control only a few seconds after that and then the aircraft dove into the ground.

There was no evidence of any powerplant or system malfunction that could hav caused the inflight explosion However, due to the inflight fire damage in the l inboard wing trailing edge, the left horizontal tail and the left side of the ver cal tail and aft fuselage, the possibility of a fuel leak in the trailing edge of the left inboard wing was explored in connection with initiation of the accident Possible sources of such leaks are the dump chute assembly, the reserve tank tra fer tube, or a rear spar crack.

Fuel released into the trailing edge could be ignited and the cavities in th wing trailing edge would act a flame holders making continued burning likely Al though the dihedral angle of the wing in normal flight would tend to cause an in- board flow of some of the released fuel along the rear spar lower edge, various obstructions in the trailing edge and chordwise discontinuities in the lower sur of the trailing edge would tend to localize any fire to the general area of the l As a result any leak appreciably inboard of the reserve tank transfer tube could be expected to cause a fire that would progress outward and heat this tube sufficiently to ignite the fuel/air mixture in the No 1 reserve tank prior to failure of the wing farther inboard. A leak in the general vicinity of the transfer tube could possibly produce this result, but the fire could not be expected to progress through the trailing edge almost to the fuselage, causing the observed inflight fire damage prior to failure of the wing near the source of the fire.

In addition, the metal splatter on the left horizontal stabilizer leading edge and inflight fire damage to the left elevator could occur only after loss of the left outer wing. In normal flight the airflow over the wing and materials separating from the wing trailing edge pass well below the horizontal tail rather than striking it and do not have the sideward component of travel displayed by the metal splatters. Also, the fire damage high on the left side of the vertical tail is wholly incompatible with fire emanating from the wing trailing edge under any normal flight conditions.

From the facts of the investigation, it has been determined that explosions occurred in the left reserve, center and right reserve fuel tanks. The wreckage distribution, supported by the fire damage pattern, leads to the conclusions that the initial explosion was in the left reserve tank and that no fire-damaged part separated from the aircraft prior to the explosion.

The exact sequence and timing of the subsequent explosions and inflight fires are not known and are, in fact, somewhat academic with respect to the probable cause of the accident. Fires were observed on both wings of the aircraft before impact. It is logically concluded that main tanks which contained fuel and are adjacent to the reserve and center tanks were structurally disrupted when some or all of the aforementioned tanks exploded; fuel was spilled and ignited. Such spillage from the opened outer end of the No. 1 main tank and fire damage to parts aft thereof, including the still attached inner ends of the outer panel rear spar and outboard aileron, are quite apparent. Early separation of the outboard engines in the sequence of events may have contributed, at least in part, to the large fires that were observed on the wings.

Although much effort was expended, the physical evidence failed to disclose the precise mechanism of ignition which triggered the explosion in the left reserve fuel tank. However, witnesses, some particularly well qualified, observed a cloud to earth lightning discharge, described as being of exceptionally great magnitude, in the immediate location from which, moments later, the burning aircraft emerged. Before observing the aircraft, a glow or light was observed in near proximity to the location of the lightning discharge. Consequently, there is a direct correlation in time and location between the lightning discharge and start of events which culminated in the accident.

Lightning discharge damage judged to be of recent origin and of an extent compatible with the reportedly observed massive lightning stroke was observed in several locations at the left wing tip area. It is pertinent to note, however, that none of the damage was on wing skin that encompassed fuel tank or vent system space of the aircraft; consequently, a direct correlation of any of this damage with the tank explosion is not possible.

Extensive and meticulous effort was expended attempting to find evidence of an electrical discharge that may have ignited the flammable mixture in the left reserve tank with negative results. The guidance and assistance of recognized authorities in the field of lightning physics and research were available and used in this phase of the investigation Particular attention was devoted to fuel quantity probes, discontinuities in the structure which form the fuel tanks bonding, fuel tank access plates, filler cap assemblies, fuel vent outlets and also tank wall surfaces. Information obtained by analyses, research utilizing laboratory produced electrical discharges and observations of natural lightning damage was utilized in determining where and how to make the detailed examination.

Although physical evidence of the means by which ignition occurred was not found, the likelihood of ignition by lightning is not ruled out. The correlation of time, place and damage cannot be dismissed. Certain phenomena associated with lightning discharges, some well defined, others more subtle and of which we have less finite information and which leave no physical evidence can ignite flammable mixtures. Probably most significant in the former category is the development of streamers from extremities and/or surface discontinuities as a lightning stroke develops in the step leader stage. These streamers have been found to be in the duration and energy range required to ignite flammable mixtures. Other phenomena, of which less is known because of generation and measuring difficulties, that are considered potential ignition sources are plasma, shock waves and sparking due to induced voltages from extremely high current rise rates that occur. Although much has been learned about lightning and its effects through research and study, many questions are still unanswered and the upper limits of voltage, current and total energy that may be associated with lightning are not conclusively defined. The apparent capricious nature of lightning is evidenced by the range of extremes as well as, in some cases, the unique nature of the damage that results. Thus, to predict in the absence of physical evidence the exact mechanism of ignition in this particular case is not possible. By the same reasoning, in view of the known facts of this accident, there is no logical explanation for ignition of the flammable vapors other than some effect stemming directly from the lightning strike

The vent system interconnects all fuel tanks and the vent outlets through passages capable of transmitting flame when filled with flammable mixtures; thus initial ignition could have occurred inside the left reserve tank, inside the left surge tank, or at the left vent outlet.

Based on evidence furnished the Board, it is reasonable to conclude that the state of the art was fully exploited within the limits imposed by basic airplane structural and configuration requirements in the design of the fuel system, including the vent outlets. Application of known lightning protection information as well as specific testing was applied during the design stages. The lightning protection requirements of the Federal Aviation Agency were satisfied.

The Federal Aviation Agency sponsored research, initiated immediately subsequent to the accident, with the intent of improving protection from ignition of fuel by lightning strikes to aircraft. The Board participated in this program by providing a member on the Committee organized to advise in the program planning and execution as well as to evaluate the results. The Committee was informed currently on the investigative results and, conversely, persons responsible for the investigation were advised as information evolved from the research activities to the mutual benefit of all responsible parties. Although the circumstances and facts of the accident were applied in the planning of the research program, its scope and intent was to provide information that could be applied industry-wide and thus was not aimed at any specific aircraft Consequently, only that portion of the program that appears to be relevant to the subject accident will be discussed.

One effort in this regard was a review by the Coordinating Research Council of all available data concerning the relative safety of Type A and Type B jet fuels and mixtures thereof. The group making this study concluded that while there are differences, the adoption of a single type of aviation turbine fuel by the entire industry would not significantly improve the overall excellent safety record of commercial aviation. The group further concluded that additional research into the nature and effect of lightning strikes and electro-static discharges is warranted and that more information is desirable regarding the phenomena of fuel spray, misting, and localized vapor-air mixtures in tanks under actual flight conditions. The Federal Aviation Agency is implementing research and test programs to accomplish, in the main, the Coordinating Research Council's recommendations.

It was demonstrated that direct lightning strikes to over wing filler caps and access plates of the configuration used on the aircraft in question can produce sparks inside the fuel tank. No evidence of a direct strike was found on these parts from N709PA. Practical means whereby these potential hazards can be eliminated, as demonstrated within the limits of the testing facility, were developed and, in the case of access plates, have already been applied to aircraft in service. Testing failed to demonstrate any hazard from induced voltages in the fuel quantity measuring system. A complete wing section of essentially the same configuration as B707-121 was tested for internal sparking in the reserve tank. Simulation of lightning strikes to the extent of the testing facility capability did not produce any recorded evidence of sparking within the tank

The testing facility that was used is recognized as being among the most proficient in the field of lightning simulation and research. It is felt that the current state of the art does not permit an extension of test results to unqualified conclusions of all aspects of natural lightning effects. The need for additional research is recognized and additional programming is planned.

## Probable Cause

The Board determines the probable cause of this accident was lightning-induced ignition of the fuel/air mixture in the No 1 reserve fuel tank with resultant explosive disintegration of the left outer wing and loss of control.

BY THE CIVIL AERONAUTICS BOARD:

/s/ ALAN S. BOYD
Chairman

/s/ ROBERT T. MURPHY
Vice Chairman

/s/ CHAN GURNEY
Member

/s/ G. JOSEPH MINETTI
Member

/s/ WHITNEY GILLILLAND
Member

# S U P P L E M E N T A L   D A T A

## Investigation

The Civil Aeronautics Board was notified of this accident on December 8, 1963, and an investigation was immediately initiated under the provisions of Title VII of the Federal Aviation Act of 1958, as amended. A public hearing was conducted as part of this investigation at Philadelphia, Pennsylvania, February 24-26, 1964.

## Air Carrier

Pan American World Airways, Inc., is a New York corporation with headquarters at New York City, New York.

The company operates as a scheduled air carrier under a currently effective certificate of public convenience and necessity issued by the Civil Aeronautics Board, and an operating certificate issued by the Federal Aviation Agency.

## Flight Personnel

Captain George F. Knuth, age 45, held a current air transport pilot certificate No. 796-40 issued April 20, 1953, with type ratings in B-707, DC-6, DC-3, and L-49. He also had navigator's rating. Captain Knuth had 17,049 hours total flying time of which 2,890 hours were in the B-707 His last Class I physical examination was accomplished in December 1963 and no waiver was required.

First Officer John R. Dale, age 48, held a current air transport pilot certificate 450373 issued November 14, 1955, with type ratings in the B-707, L-49, B-377, and navigation. He had a total of 13,963 hours flying time of which 2,681 hours were in B-707 aircraft. His last physical examination was completed in August, 1963, with no waivers.

Second Officer Paul L. Orringer, age 42, held an air transport pilot certificate 220082, issued April 6, 1962, with type ratings in DC-6, DC-3, and navigation. He had 10,008 total flying hours including 2,808 in B-707 aircraft. His last physical examination was completed in June, 1963, with no waivers.

Flight Engineer John R. Kantlehner, held an aircraft and powerplant mechanic certificate and a flight engineer certificate. The latter was issued December 14, 1955. He had a total flying time of 6,066 hours including 76 hours in the B-707. His last physical examination was completed October 1, 1963, with no waivers.

The cabin attendants were properly trained and qualified for the positions in which they were serving.

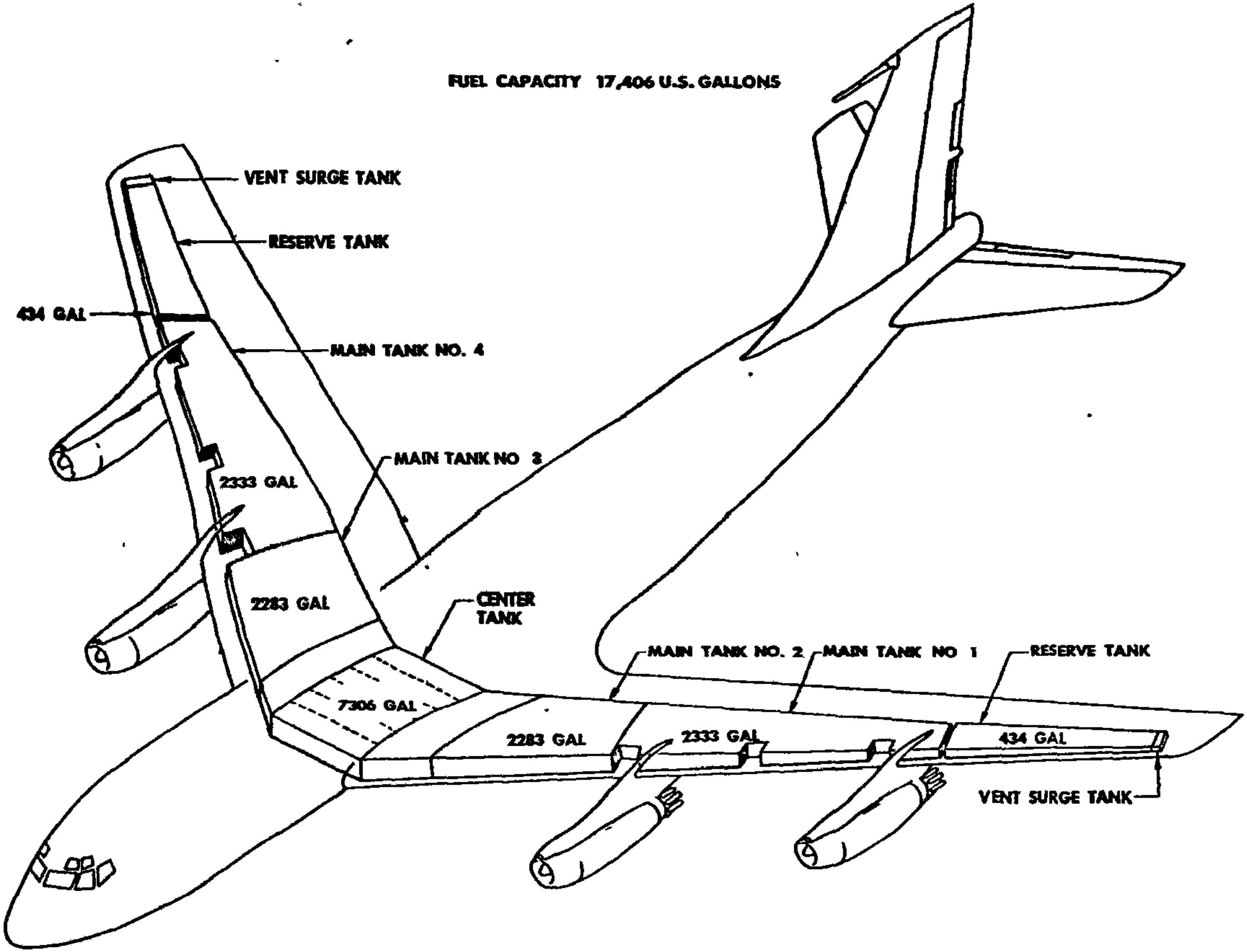
## The Aircraft

The aircraft, a Boeing 707-121, N709PA was purchased by Pan American in 1958, and had a total flying time of 14,609 hours. The last major inspection was performed March 25, 1963, and the last layover transit inspection December 7, 1963.

## The Powerplants

The aircraft was powered by four Pratt and Whitney JT3C-6 turbojet engines. The total time (TT) and times since overhaul (TSO) of these engines were:

| Engine No. | TT (Hours) | TSO (Hours) |
|---|---|---|
| 1 | 8593 | 618 |
| 2 | 8328 | 1419 |
| 3 | 8623 | 3149 |
| 4 | 9446 | 2371 |




FUEL TANK ARRANGEMENT

COPY

ATTACHMENT II

B-80-96

DEC 17 1963

Mr. George S. Moore
Director
Flight Standards Service
Federal Aviation Agency
Washington, D. C., 20553

Dear Mr. Moore:

The investigation to date of the Pan American World Airways, Inc., Boeing 707-121, N709PA, aircraft accident near Elkton, Maryland on December 8, 1963, has identified in a gross sense the causal areas. That an inflight explosion occurred in the No. 1 reserve fuel tank is readily evident. It is believed the explosion stemmed from ignition of combustible fumes at the fuel tanks vent outlet by a lightning strike. Positive evidence of lightning striking in the wing tip area, some near the vent system outlet, has been noted. The investigation, to attempt to more precisely define the mechanism of initial ignition and progress to explosion, is continuing.

Fuel aboard at the time of the accident was approximately a 68/32 Jet A/Jet B by volume mix. Based on data furnished by PAWA, it is estimated the temperature of the fuel was approximately 42 degrees F. Except for normally unuseable fuel, all was being carried in the four main tanks. Considering all factors, it is concluded the fuel vapors in all tanks were within the flammability limits.

This accident has focused attention on a serious problem; not new as evidenced by the studies previously made and the great number of reports and papers dealing with it. There is no doubt in our mind that our concern regarding this matter is shared equally by yourself and staff. It is appreciated also that immediately attainable corrective measures to provide total protection are not readily evident. However, we do feel and urge that all available government and industry resources should be marshalled to implement protective measures. Even partial measures effecting definite improvement appear warranted before the ultimate protection can be provided.

The following recommendations for your consideration are submitted:

1. Install static discharge wicks on those turbine powered aircraft not so equipped.

2. Reevaluate problems associated with incorporation of flame arrestors in fuel tank vent outlets We believe positive protection against fuel tank explosion from static discharge ignited fuel/air mixtures at fuel tank vent outlets can be provided by flame arrestors having sufficient depth

3. A possible alternate to No 2 that may be considered is to render the mixture emitting from the vent outlet non-ignitable by the introduction of air into the vent tube.

4. We believe the surge tanks located just outboard of the reserve tanks, by virtue of their location near the wing tip, are vulnerable with respect to lightning strikes Burn marks on the skin in the tip area of N709PA substantiates this belief This being the case it is believed a measure of protection will be attained if the wing skin is not utilized as part of the surge tank walls This could be accomplished by providing an inner wall with an air gap between it and the wing skin to form the surge tank. It is recommended that this concept be considered Another alternate appears to provide sufficient thickness of the skin in this area to prevent burning through by lightning strikes

5 Suggested for consideration is the requirement that only Jet A fuel be used commercially. Vapor flammability temperature limits charts provided by Esso show that much less of the operations would occur with the vapor in the flammability range while using Jet A fuel as compared with Jet B fuel

6. Finally, it is recommended that every effort be expanded to arrive at a practical means by which flammable air/vapor mixtures are eliminated from the fuel tanks. There appears to be at least two approaches to accomplish this aim. There is the possibility of inerting the space above the fuel by introduction of an inert gas An alternate approach is to introduce sufficient air circulation into the tanks to maintain a fuel/air ratio too lean for combustion There may well be other approaches to attain this goal; if so, they should be explored Other problems of like complexity have been resolved and we feel the resolution of this problem is likewise attainable at a cost commensurate with the benefits We recommend that FAA/CAB solicit the aid of the aviation and petroleum industry as well as government and defense agencies to provide a solution to this problem that is applicable to aircraft in service as well as new aircraft

The above recommendations amplify our telephone conversation of December 11 and our meeting on December 12. Through your participation in the investigation of the accident as well as by direct contact from this office, you will be advised of current developments as well as of any other thinking we may have regarding corrective measures. My staff will also be available for any assistance we can provide to resolve this safety problem.

Sincerely yours,

Original signed by
Leon H. Tanguay

Leon H. Tanguay
Director, Bureau of Safety

ATTACHMENT III

FEDERAL AVIATION AGENCY
Washington 25, D C 20553

MAIL ROOM
MAR 13 8 37 AM '64

MAR 1 2 1964

Mr. Leon H. Tanguay
Director, Bureau of Safety
Civil Aeronautics Board
Washington, D. C. 20428

Dear Mr. Tanguay:

This will supplement our January 2, 1964, acknowledgment to your letter, reference B-80-96, dated December 17, 1963, regarding the Pan American World Airways, Inc., Boeing 707-121, N709PA, aircraft accident near Elkton, Maryland, on December 8, 1963.

The recommendations and suggestions offered in your letter of December 17, 1963, have been carefully considered along with other ideas for achieving improved protection against lightning strikes. This Agency is engaged in a program of studies, tests, and investigations to provide information essential to the development and application of superior protective measures.

Although the investigation of the accident has not yet disclosed evidence of the mechanism by which a lightning strike ignited the fuel, we have applied certain precautionary measures, each of which offers some degree of benefit. These are:

NOTAM issued on December 13, 1963, alerting pilots and traffic controllers to lightning hazards, need for thunderstorm avoidance, and encouraging use of PIREPS.

Telegram to air carriers and aircraft operators, on December 18, 1963, recommending the installation of static dischargers on all aircraft using turbine fuels.

Airworthiness Directive on Boeing 707, 720, and 727 series aircraft, requiring modification of fuel tank access door bonding, issued on February 4, 1964, as an adopted rule.

Airworthiness Directive on Boeing 707 and 720 series aircraft, requiring overlay on surge tank skin for improved protection against penetration, issued on February 21, 1964, as an adopted rule.

Information on all aspects of our program was given by the Federal Aviation Agency witnesses in testimony before the Board of Inquiry at Philadelphia on February 25. This letter, therefore, is limited to a brief account of program status.

Technical Committee

A Technical Committee on lightning protection for aircraft fuel systems has been formed, composed of representation from the FAA, Civil Aeronautics Board, National Aeronautics and Space Administration, U. S. Weather Bureau, U. S. Air Force, and U. S. Navy. The Committee has been meeting regularly and is providing guidance and assistance in planning and carrying out specific actions.

Installation of static dischargers

The response to the telegraphic recommendation of December 18, 1963, has been completely favorable. Installations are being made as parts become available. Late reports show that about 24 air carrier airplanes are yet to have dischargers installed. Availability of parts is the main factor in completing the remainder.

Collection and analysis of data

We are receiving lightning strike data from all available sources. These data are being consolidated and analyzed with the assistance of the Technical Committee.

Contract with Atlantic Research Corp. (FA64WA-4955, dated January 30, 1964, Amount, $70,259.00)

This work includes the evaluation of flame arrester designs for effectiveness, and studies and tests on other ways of protecting the vent system - such as explosion suppression and ventilation of vent outlet. Equipment calibration tests are now being conducted.

Contract with Lightning and Transients Research Institute (FA64WA-4960, dated February 4, 1964, Amount, $96,748.95)

This contractor is investigating the internal arcing possibility on typical wing tank construction, and will evaluate means of eliminating any arcs found to exist. Later, proof tests of promising flame arrester designs will be conducted. The test article is in place and initial discharges are being fired to check out the equipment.

Planning for comprehensive research and development projects

A more comprehensive program of research and development will be required for the purpose of refining design criteria, making advanced studies of protection concepts - in general covering areas of investigation not possible in the short-range contracts with Atlantic Research Corp. and LTRI. The Technical Committee is now considering suggestions for the scope and nature of the projects.

Fuels study

The questions which have been raised concerning the relative safety of JP-4, kerosene, and mixes of the two are being studied. To assist in the resolution of these questions, we have asked the Coordinating Research Council to undertake a review of all available data on the subject. The CRC is proceeding with this work, which will serve to define the "state of the art," identify areas where research may be needed, and recommend how to accomplish any needed research. In addition, we have issued Advisory Circular No. AC 20-20, which furnishes some general information on the subject.

Reevaluation of aircraft in service

Based upon information now at hand, later to be supplemented by information derived from the contract work and from the accident investigation, we are proceeding with a reexamination of the basis for approval of lightning protective features of all turbine-engined aircraft.

Through your Mr. Hallman's participation as a member of the Technical Committee, we are receiving information on the continuing work by your investigators, and he is being regularly informed of the status of lightning program plans, actions, and results. We believe that the collective efforts being applied to this program will be successful in producing practical ways and means for improved protection.

George S. Moore
Director
Flight Standards Service