course indicator, the azimuth ring will remain at rest and cannot be moved by vibration or shaking. If the power interruption occurs while the ring is rotating, there will be a short coasting period before stoppage. The maximum rate of turn of the ring is approximately 3 rpm. which represents a very high aircraft turning rate. If electrical power to the instrument is interrupted at that rate of turn an overshoot of approximately 20 deg. will occur. The approximate average rate of turn of the aircraft immediately after takeoff was 1 rpm. If power were interrupted at that rate the overshoot would be approximately six to seven degrees. The lag between compass system heading indication and course indicator azimuth ring heading indication would be approximately one to two degrees at high rates of turn. It is apparent, in this instance, that lag and overshoot values are not of sufficient magnitude to be of significance. Considering this, together with the lack of impact damage and the insensitivity of the azimuth ring mechanism to external forces, the heading indications found must represent, quite accurately, the readings of the instruments and, consequently, the headings of the aircraft at the time power to these instruments was interrupted.

Compasses Stop

The 10 deg. difference in heading readings indicates that the two compass systems became inoperative at different instants during the slide of the aircraft. Initial contact of the aircraft was on a heading of approximately 285 deg. and the final heading was 241 deg.

It appears that the first officer's compass system stopped functioning first at a 282-deg. heading. This was followed by failure of the C-2A system at a 272-deg. heading. One possible explanation of this behavior is that the A-12 Gyrosyn compass system units, which drive the first officer's course indicator azimuth ring, were located in the fuselage belly and might have been destroyed before the C-2A Gyrosyn compass system was affected, its components being above the cabin floor level.

The Board gave consideration to the possibility of the two azimuth rings having failed to rotate during the turn owing to some unknown malfunction that caused their respective compass systems to "hang-up" or hold the runway heading and, that following breakup of the aircraft, wherein the tail section was nearly separated, the flux valve wiring was destroyed permitting the magnetic slaving systems of the gyro compasses to precess them to the heading indications found.

The preceding hypothesis has been found unacceptable for several reasons. Simultaneous failure of two separate compass systems would be necessary. The maximum precession rate that could be commanded by the flux valve slaving system is approximately five degrees per minute; which means that a minimum period of 25 to 27 min. would be required. This is considerably longer than the time required for fire to render the instruments inoperative.

Finally, electrical power would not have been available for so long a period. When engine rotation ceased all generator output was lost and the batteries became the only source of electrical energy. They, being located in the fuselage belly, were most probably destroyed early in the slide of the aircraft.

The captain testified that the C-2A Gyrosyn compass indication was checked and found to be normal when the aircraft was in the runup position. The aircraft heading at that time was approximately 280 deg. Shortly thereafter the instrument was again observed while the aircraft was in takeoff position and it was indicating 43 to 44 deg., which agrees with the heading of runway 4. This indicates normal operation of the instrument up to that point.

Compass Card Data

The captain's course indicator azimuth ring receives its heading information from the C-2A Gyrosyn compass and its reading of 272 deg. after the accident indicates that the C-2A operated normally during the flight. The captain testified that he referred to the C-2A Gyrosyn compass for heading information and saw no indication of the turn made by the aircraft, only headings of approximately 40 deg. to 45 deg. being observed. To have occurred, the compass card of the C-2A would have had to become disconnected from its shaft after the aircraft was lined up on the runway. It would then, in some unexplained fashion, have had to indicate response of the aircraft to control actions in changing heading between 40 deg. and 45 deg. as the captain testified. Finally, in the period of time after the captain stopped viewing his panel until the instrument was destroyed in the ground fire, the disconnected compass card would have had to rotate to the 153-deg. heading indication at which it was found.

A more plausible explanation of the occurrence is that the instrument behaved normally throughout the flight. Electrical power to the course indicator was interrupted after impact, causing the azimuth card to remain at a 272-deg. heading indication.

When fire consumed the instrument panel the C-2A Gyrosyn compass was released and fell, allowing the gyro assembly to go into gimbal lock condition. With the gyro still coasting, precession would cause the compass card to rotate until gyro rotation ceased.

Fire marks on one of the eight-day panel clocks indicated that fire destroyed the clock at seven minutes past the hour. This indicates that the instrument panel was involved in fire approximately five minutes after the accident occurred. The gyro of a C-2A Gyrosyn compass will coast for approximately 12 min. after power interruption and it is reasonable to assume that the magnesium instrument panel was destroyed within that period of time.

A similar occurrence of gyro precession is indicated in the case of the A-12 Gyrosyn compass which was found at an approximate heading of 179 deg. while its repeater, the azimuth ring of the first officer's course indicator, indicated a 282-deg. heading.

The captain recalled that he checked his gyro horizon indicator before takeoff and that it was in a level condition and appeared to be normal. He did not recall whether or not he caged it; however, the caging mechanism is spring-loaded to the uncaged position and the gyro becomes uncaged when the caging knob is released. Also, while the instrument is caged a warning flag appears behind the cover glass.

The first officer recalled that he checked his turn-and-bank indicator and found its operation normal before the takeoff.

The captain's turn-and-bank indicator and gyro horizon indicator received their electrical power from the secondary side of the captain's instrument transformer. Similarly, the first officer's turn-and-bank indicator and gyro horizon indicator received their power from the first officer's instrument transformer. It is to be expected, therefore, that if one of the two paired units was operating normally, as the crew had indicated, its companion instrument would also be operating normally, discounting individual instrument failure or failure of circuit wiring common to only one of the two paired instruments.

If satisfactory operation was obtained during the runup prior to takeoff, indications of turn and attitude would be expected during the very short period of flight that followed. Even if all electrical power were removed from normally operating instruments, indications of heading changes and attitude would be available for some time afterward as gyro speed decreased.

Tests that were conducted on a similar aircraft, N 34953, at Chicago, Ill., March 15, 1957, showed that at least two minutes passed after interruption of electrical power before the horizon tumbled. Tests conducted later at the Eclipse-Pioneer Division, Bendix Aviation Corp., using a similar instrument mounted on a $7\frac{1}{2}$ deg. Scorsby test table showed the rundown period until the gyro tumbled to be $3\frac{1}{2}$ min. Gyro speed at that instant was approximately 1,750 rpm.

Turn indications of a similar turn-and-bank indicator were checked while the instrument was rotated at 180 deg./min. on a turntable. At normal gyro operating speed the needle deflection was one-half inch. Three minutes after power interruption the deflection was $\frac{3}{32}$ in. If the rate of turn were increased to 360 deg./min., which was the approximate average rate of turn of the aircraft from takeoff to impact, the needle deflection after three minutes of coasting would have been approximately $\frac{3}{16}$ in.

Power Effect

The effects of improper a.c. power input were also considered. Normal power required for these instruments is 26 volts at 400 cps. The manufacturer's tolerances for these values are plus or minus 10%. Various combinations of voltage and frequency were explored, the worst condition being 50% of a normal voltage at 250 cps.

With this unorthodox input, the gyro of the gyro horizon indicator operated at approximately 12,000 rpm. This is equivalent to the speed of a normally operating gyro one minute after its power supply has been interrupted. The gyro of the turn-and-bank indicator rotated at approximately 13,500 rpm. or at the speed of a normally operating gyro after approximately one minute of coasting following power interruption. Needle deflection in a 180 deg./min. turn at this rpm. would be approximately $\frac{3}{8}$ in.

The basic electrical system of aircraft N 34954 was a single-wire, ground return,