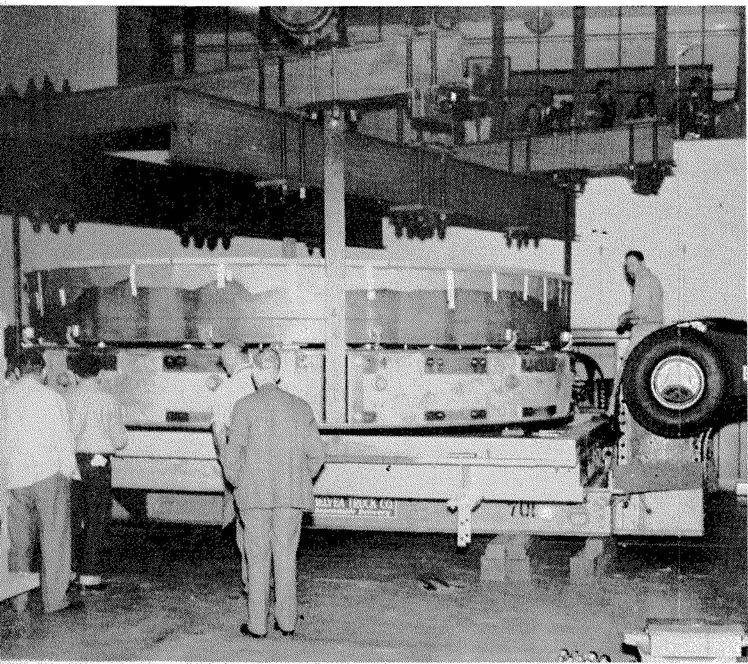

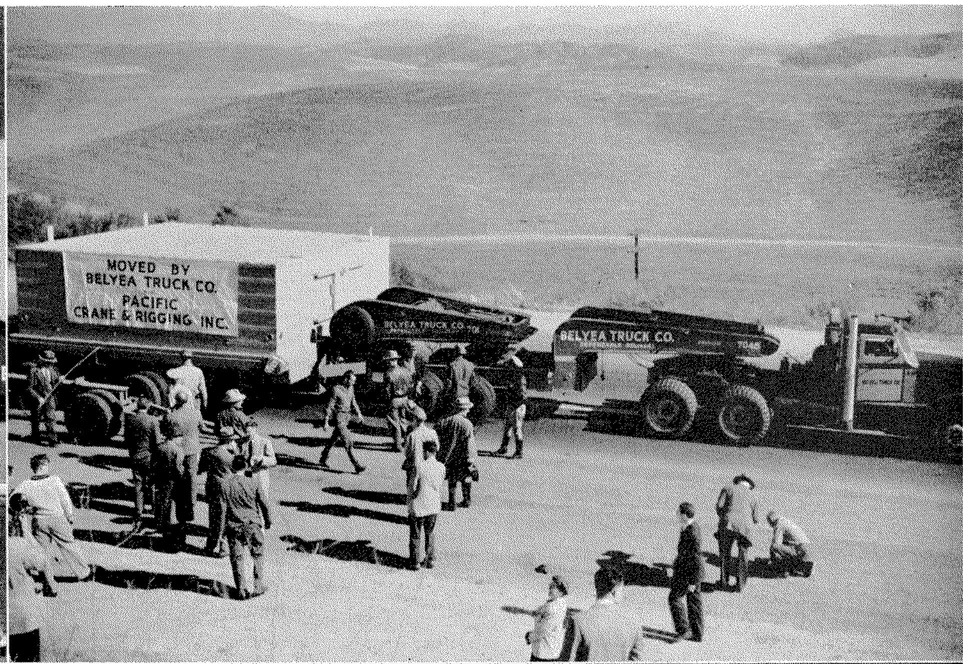

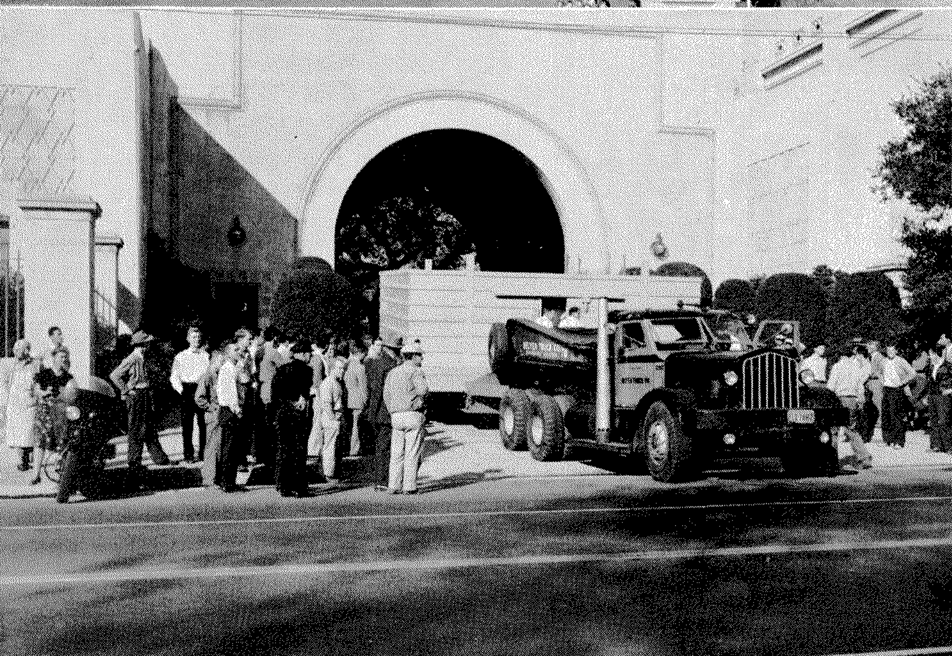

UPPER LEFT: Mirror and cell being loaded on the trailer in CalTech's optics laboratory. In the background is the glassed-in observatory gallery.

CENTER LEFT: Preparations for the trip to Palomar Mountain. The mirror and trailer made the right-angle turn out of the optical laboratory at right with three-quarters of an inch to spare. In this picture the eight-wheel dolly between truck and trailer has not yet been attached.

LOWER LEFT: Engineer Bruce Rule taking a vibration meter reading en route.

UPPER RIGHT: Caravan stopped to add two eight-wheel dollies to the trailer. This was done in order to distribute weight more evenly while crossing the Galivan Bridge on Highway 101 above San Juan Capistrano Beach.

CENTER RIGHT: Lowering the mirror into the aluminizing tank at the Palomar Mountain Observatory. The cover to the tank is not shown in this picture.

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The 200-Inch Mirror is Moved to Palomar Mountain

AT the Institute for 12 years, the Palomar mirror was finally adjudged as near perfect as any mirror could be—within two millionths of an inch of a true parabola—and was transported to Palomar Mountain to be aluminized and mounted in the completed telescope framework.

So much interest had been aroused in the big glass disc that the Public Relations Department at CalTech was hard put to keep information as to when the 200-inch mirror would be moved a secret. The keeping of the secret was made possible by excellent cooperation from newspapers, radio stations and similar agencies. All CalTech knew, however, as preparations commenced a few days before the moving date and a huge semi-trailer was eased into the windowless air-conditioned optical laboratory by sheer manpower.

On Sunday November 16, the mirror, finished since early October, was attached to its 20-ton cell by which it will be mounted in the telescope. Then, slowly, the 35-ton assembly was carried the length of the optical laboratory, suspended by 12 steel cables from 5 overhead tracks.

Swinging like a pendulum bob, but never enough to be dangerous, the huge glass disc was brought down the long 120 feet of the laboratory. After stops for photographs, it was lowered on the semi-trailer adapted for this operation. The mirror was drawn into position by hand onto the trailer bed. Padded side pieces were bolted on, and the lid, a great gray packing box, was moved into a covering position. Only paper and plyboard were actually in contact with the surface of the mirror.

On Monday, the trailer was dragged out of the optics laboratory by winches, and attached to the truck. That afternoon saw the truck and trailer lined up outside the laboratory, with a police officer already controlling traffic. Ropes around the mirror kept the curious at a distance.

At 3:30 a.m. Tuesday, the diesel truck swung into California Street, stopped briefly for more news photographs, and then set off at a speed of five miles per hour, surrounded by a caravan of newsmen and police cars.

Vibration was the chief bugaboo of the astrophysicists, as they shepherded their pride and joy over the 160-mile journey to Palomar Mountain. Crystal pickups installed on the trailer were attached both to a dial in the truck cab and to recorder that produced a permanent trace of the vibrations encountered on the trip. The speed of the truck, governed by the truck cab indicator, varied between 5 and 15 miles per hour.

On schedule, the caravan reached Escondido at 5 p.m. Tuesday after an uneventful trip. Five bridges received aditional shoring to support the 40-ton combined weight of truck, trailer, and its precious load. To cross one coast highway bridge, dollies were placed beneath the trailer, providing a total of 58 wheels to distribute the load more evenly. Recorded deflection of the bridge was three-eighths of an inch.

Twelve hours after the Escondido arrival, the second and last leg of the journey commenced, with the diesel tractor receiving assistance from two pusher units, deemed necessary because of the slippery mountain roads. In spite of poor road conditions and a dense fog which reduced visibility and photographic activity, the mirror reached the Observatory at 11 a.m., seven hours ahead of schedule.

Promptly the mirror was transferred to the aluminizing tank where, in a high vacuum, a layer of aluminum three molecules thick was distributed evenly over its surface.* It is now in the closed tank, awaiting completion of preparations for mounting in the skeletal telescope framework.

The installation, testing, and final adjustments will permit CalTech astronomers to photograph the universe with greater clarity and to greater distances (one billion light years) than ever before. The greater light-gathering power of the 200-inch mirror may answer some of the basic questions of astrophysicists: "Is the universe somehow limited? Is it expanding? Are there galaxies similar to our own at regular intervals throughout space? What is the source of stellar energy? What are the origins of the chemical elements?"

The 200-inch mirror disc was cast in 1935 by the Corning Glass Works and arrived in Pasadena in April 1936. It was unpacked on Easter Sunday of that year and on April 22 it was placed on the grinding and polishing machine. At that time it weighed approximately 20 tons. In grinding and polishing, approximately five and one-quarter tons of glass were removed. To do this required 31 tons of abrasives.

Of the glass removed from the disc, two and one-half tons were ground away in shaping its concave surface. With the disc lying horizontal, its concave face

*Details on the general technique used in aluminizing may be found in ENGINEERING AND SCIENCE for December 1947.

(Continued on page 8)

turn indicator, he will still find it possible to picture the attitude of his aircraft and to fly in a coordinated manner. It is only necessary that he know the characteristics of performance of the type of airplane he is flying. For example, if the altimeter reading is constant, the turn needle and ball are centered, and the power is set for cruising, the pilot can assume that he is in level flight at a certain air speed. If the altitude increases uniformly 500 feet each minute, the turn needle is deflected by its own width, the ball is centered, and the power is set for a normal climb, the pilot can visualize himself as executing a climbing turn at a safe air speed. He also knows that he is turning at a rate of three degrees per second (if the turn needle is so calibrated) so that if his compass is inoperative he can make any desired turn by reference to the time.

In order to fly successfully with a reduced number of instruments, the pilot must learn to extract as much information as he can from the few instruments which are operating. The most important source of "hidden information" lies in the fact that instruments show rates of change as well as actual readings. Much can be learned about the attitude of an airplane from the rate at which air speed is changing; a safe air speed which is decreasing rapidly indicates a more dangerous attitude than does a dangerously low air speed which remains constant.

The possibility of prolonged flight solely by reference to the magnetic compass affords an extreme example of the usefulness of a single instrument. The magnetic compass is subject to two effects which are ordinarily objectionable but which can be used in emergencies to yield information not usually associated with a compass. These effects arise from the fact that whenever the compass is tilted to the eastward or westward it is acted upon by the vertical component of the earth's magnetic force and is caused to turn to a new position of equilibrium. Such a tilting occurs when an aircraft headed north or south begins to turn; this "northerly turning error," the first of the two effects, vanishes when the aircraft is headed east or west. The tilting also arises when an aircraft headed east or west gains or loses speed; the inertia of the freely suspended compass causes it to tilt to the eastward or westward. This second effect, the "acceleration error" vanishes when the aircraft is headed north or south.

If all instruments except the magnetic compass should become inoperative (the magnetic compass is the most rugged of the instruments and the least susceptible to failure), the pilot should first turn to a heading midway between north or south and east or west. At one of these headings both northerly turning error and acceleration error will be appreciable. The pilot is then warned of any tendency to turn by the very sensitive northerly turning error, and he is apprised of any rapid climbs or dives by the less sensitive but adequate acceleration error. He can detect a gradual gain or loss of speed by increasing or decreasing responsiveness of the airplane to pressures upon the controls. Thus the pilot can maintain controlled flight until he has flown clear of the instrument weather area.

THE IMPORTANCE OF SELF-CONFIDENCE

The greatest asset to competent instrument flying is self-confidence, gained through constant practice in flying by means of a limited number of instruments and under actual instrument weather conditions. The self-confident pilot is able to think clearly and constructively; his thoughts are not diverted by fear and doubt.

Practice under an instrument flying hood is a prerequisite to flying in actual instrument weather, but it is not a perfect substitute. Every pilot is tense and apprehensive when he first finds himself "in the soup," and it is not until he has flown many times under actual instrument conditions that he acquires the full assurance which enables him to fly well by instruments and to deal efficiently with emergencies.

CONCLUSIONS

In summary the following conclusions may be drawn:

1. When flying by instruments the pilot must form a mental picture of the attitude of his aircraft from the indications of his instruments
2. In instrument flight, the pilot must make deliberately some control movements which seem instinctive in contact flight. These movements are stimulated by small changes in attitude under contact conditions; the instruments are too insensitive to produce these stimuli
3. The pilot must disregard all sensory illusions in flight and must determine his attitude solely from the indications of his instruments
4. The pilot must be physically relaxed to fly well and to avoid hypnosis and illusions of leaning
5. When some instruments are inoperative, the pilot can usually derive enough information from the remaining instruments to continue normal flight under instrument conditions
6. The pilot must have complete confidence in himself, gained only through frequent practice in actual instrument weather, if he is to fly efficiently by instruments and avoid accidents in emergencies.

The 200-Inch Mirror is Moved to Palomar Mountain

(Continued from page 5)

would provide a basin large enough to hold approximately 256 gallons of water. Approximately 24 inches thick at the edges and 20¼ inches at the center, the mirror has a solid face approximately four inches thick. Ribbing on the back accounts for the much greater actual dimension. In its center is a hole 40 inches in diameter, which incidentally is exactly the same diameter as the largest refracting telescope lens at Yerkes Observatory. During grinding and polishing this hole was plugged. Installing the big glass plug, a much greater engineering problem than its removal, was accomplished by the simple method of placing the plug on a cake of ice which protruded above the surface the disc. As the ice melted, the plug sank slowly into position.

Although work on the mirror started 11 years ago, World War II brought a halt for four years. Those working on the mirror turned to war projects, and in the same room where the mirror awaited the end of hostilities, critically needed optical work was done. A number of mirrors, some of them 36 inches in diameter, were ground and polished for the armed forces and sent to such places as the Aberdeen Proving Ground, Wright Field and Langley Field. Approximately 1100 right-angle prisms were made for the armed forces in adition to other optical work.

Work was resumed on the 200-inch mirror on December 17, 1945 and continued until October 3, 1947. Approximately 180,000 man-hours were required to grind and polish it.