ment at night and when not in use. The other building, which we call the shop, is 30' by 50'. It is large enough to accommodate any of our equipment needing repair. It is heated by a stove. The tools in the shop include a welding outfit, a cutting torch, an air compressor, a vice, an anvil, and a work bench with a rack for all kinds of small repair parts, such as bolts and spark plugs. We do not carry a large stock of repair parts, as we are within 20 miles of Indianapolis and can get almost any parts needed in two hours' time. We have ample room in the shop so that on bad days we are able to do quite a lot of miscellaneous work, such as painting signs. We also mix the patching materials for blacktop roads inside. The gravel is mixed with the bituminous material and stock-piled inside of the building. Having this material mixed in advance enables us to repair more roads on good days.

All hands report for work at 6:30 A. M. and, at once beginning to get their equipment ready, leave the shop by 7:00 A. M. They work until 4:30 in the evening. We have one mechanic who works in the shop and is ready for emergency calls at any time.

MAPPING AIRPLANES AND THEIR FUTURE

Talbert Abrams, President,
Abrams Aerial Survey Corporation
and
Abrams Air Craft Corporation,
Lansing, Michigan

A discussion of aircraft for aerial photography, surveying, sketch mapping, reconnaissance, or observation should best consider the past, the present, and the future.

THE PAST

I find in the Patent Office of the United States in Washington patents on methods of mapping, patents on aerial cameras, patents on stereoscopes and other devices which could be used for contouring, and patents on various types of airplanes and contrivances for flying. From a study of all these patents, most of which have never been put into production or general sale and most of which are outlawed by age, a complete story of the progress of aerial mapping equipment, including airplanes, cameras, and accessories, is told. Slow progress was made in the development of equipment for aerial surveys prior to the World War. Since 1918, progress has been rapid. New methods for aerial surveys have been used each year and aerial surveying is a well-established industry.

For the past twenty-five years, aviators have cut camera holes in all types of airplanes and added special windows in
sides and floor of fuselage in order to make the best of a bad situation, knowing it was only a means to an end.

THE PRESENT

In the United States and abroad, aerial photography is urgently needed to solve immediate and present problems. Specifications are being written to take advantage of available airplanes, cameras, and the personnel to operate them. Government departments and private interests have need for aerial surveys of greater accuracy than is possible with present-day equipment. Government experts no doubt have tentative specifications written which will be held until equipment and personnel are available to make still more accurate surveys.

THE FUTURE

The three million square miles in the United States and the fifty-six million square miles of land in the world, less than 5% of which has been effectively mapped, present a big job to be done; and special equipment must be produced to do the job efficiently.

It has been my pleasure to consult with many photographic pilots, cameramen, owners of planes, and users of aerial photographs, and their problems are briefly enumerated as follows:

Photograph users say, “Photographs will have to be more accurate; smaller scales can be used; the price will have to be less to justify their use; special planes will have to be developed which fit the job.”

Cameramen say, “We must be more comfortable to do better work; we need better cameras, view finders, and instruments; planes must be faster and have a more rapid climb to altitude, for too much time and mapping weather are lost while climbing; planes must be stable, fore and aft and laterally, if tilt is to be eliminated; we must also be able to see.”

Pilots say, “Visibility must be perfect; noise and vibration must be reduced so that pilot and cameraman can converse back and forth, and work a full day without undue fatigue; oxygen and super-charging of gondola must be effected to make high altitude flying practical; the size and expense of a large plane is not necessary to do a two-man job; perfect stability, mechanical pilots, and instruments are absolutely necessary; long economical cruising range is efficient; the plane must have built-in course-holding lateral and vertical stability.”

Reviewing these opinions, we find a definite need for planes of high speed, 100% forward and downward visibility, light wing loading, high power loading, superchargers for motors, a sealed gondola, all known navigational aids and instruments, an eight-hour fuel supply, constant speed propellers of special design, special cameras to take full advantage of all these features.
Let us see what each of these features means to the aerial survey industry.

High speed on flight lines means getting more square miles covered in each hour and minute of photographic weather. Each ten-miles-per-hour increased speed at standard specifications, scale 1:20,000, in a four-hour day at the average prices prevailing today means an extra gross income of $200 per day. A 100-mile-per-hour increase in speed over standard planes now in use means $2,000* per day more mapping completed.

Forward and downward visibility of 100% means greater ease in keeping on flight lines, quicker turns to come on the line, less fatigue and worry to the pilot. Taking the record of the past year in the North Central Division, Agricultural Adjustment Administration, wherein 61,144 square miles of reflights were necessary—this is 29.7% of all flying done—and considering that not one-half but perhaps one-fourth of them could have been prevented by better visibility, you have a sizable amount that might be saved. This is well sectioned country and probably the best area in the United States to map. In the East Central Division of the United States, one area required 40% reflights.

Light wing loading and a high power loading mean stability and performance. The average plane on government mapping today takes forty minutes to one hour to get 15,000 feet altitude—save half of this time and you have an additional $300 of mapping completed on each flight.

An eight-hour fuel supply is necessary if full advantage is to be taken of all suitable weather. At an altitude of 15,000 feet a 450 h.p. supercharged motor will use 20% less gasoline than a 285 h.p. unsupercharged motor in planes which are comparable, and with a plane with a 450 h.p. supercharged motor the speed will be 10% greater than with a plane having a 285 h.p. unsupercharged motor, all other things being equal.

In operating at altitudes, one is faced with the problem of decreasing air density. This can be thought of as reducing the efficiency of both the personnel and the power plant. Varying of course with different individuals, men and engines, this starts becoming important at an altitude of around 14,000 feet. At 20,000 feet the average man is unable to function for any great length of time without oxygen, and the engine only puts out 45% of its sea level power. A 145 h.p. unsupercharged motor at 15,000 feet delivers only 57% of its rated h.p., or 83 h.p., and speed is decreased in proportion.

Quoting in round figures, the relative air pressure is:

<table>
<thead>
<tr>
<th>Altitude</th>
<th>Relative Pressure</th>
<th>Sea Level</th>
<th>lbs. per sq. in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level</td>
<td>100%</td>
<td>100%</td>
<td>14.7</td>
</tr>
<tr>
<td>10,000 feet</td>
<td>69%</td>
<td>69%</td>
<td>10.3</td>
</tr>
<tr>
<td>20,000 feet</td>
<td>46%</td>
<td>46%</td>
<td>6.7</td>
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<tr>
<td>30,000 feet</td>
<td>30%</td>
<td>30%</td>
<td>4.5</td>
</tr>
<tr>
<td>40,000 feet</td>
<td>19%</td>
<td>19%</td>
<td>2.8</td>
</tr>
</tbody>
</table>

* Prices based on $2.50 per mile.
The relative density of air pressure is slightly greater at high altitudes because of the lower temperatures.

Measurements of the power of conventional aircraft engines at various pressures vary in practically the same proportion. These show approximately the same reduction in power up to 20,000 feet as the reduction in air pressure. Above 20,000 feet, the power falls off rapidly to 25% at 30,000 feet and 11% at 40,000 feet.

By using supercharged engines with built-in blowers and oxygen inhaling equipment for the crew, mapping operations can, with the attendant difficulties, be carried on up to 25,000 feet. Above that the engines need an additional stage of supercharging and ordinary oxygen dispensing equipment is inadequate.

We offer the suggestion of using the cabin or gondola as your second stage of supercharging, packing air into the gondola with an exhaust turbine blower or auxiliary compressors, and feeding the carburetor direct from the gondola. This has some advantages in decreasing weight and conserving horsepower. In supercharging air the temperature is automatically raised, and this eliminates the necessity for additional heating equipment. Supercharging is commercially practical up to altitudes of 40,000 feet at the present time, and this means supercharging back to a reasonable altitude of twelve to fourteen thousand feet. Sea level pressure of 14.7 pounds per square inch decreases to 6.7 pounds at 20,000 feet. By pumping 1.9 pounds air pressure into the gondola, 14,000 feet pressure is maintained at 20,000 feet. By keeping a pressure of 8.6 pounds per inch, or a 14,000-feet condition, as you go into still higher altitudes, comfortable working conditions are maintained. Oxygen has to be fed into the air stream. Instruments are now available to record oxygen content in the air, and they also indicate the pressure. About ten cubic feet of air per minute per person is required, the two-man mapping crew requiring about twenty cubic feet per minute.

Because the resistance of the air is decreased as the pressure lessens, an increase in speed of 36% can be expected in planes of proper design at 30,000 feet if the motor has been supercharged to deliver its rated sea-level horsepower by supercharging up to 14,000 feet. This means that speeds exceeding 300 miles per hour can be expected in the new mapping planes built for the job.

The ceiling of an airplane varies in an inverse ratio to the power loading and the square root of the wing loading; that is, doubling the power would have the same result as increasing the wing area four times, provided of course, that weight and other factors remain comparative.

Constant speed propellers and special curves to reduce tip speeds at low temperatures and rarified air are absolutely
necessary. If propeller tip speeds are allowed to approach the speed of sound, their efficiency is reduced and, because the speed of sound drops in the extreme cold and rarefied air of the stratosphere, special wider blades or three- or four-bladed propellers will have to be used.

Camera manufacturers will have to take supercharged cabins into consideration because camera port holes must be sealed. This should also be done even for low flying to protect the cameraman from the chill of cold wind and gas from the motor.

Considering the sealing of the camera hole, we offer two suggestions. First, that the camera be sealed so that no air could escape through the joints between lens-shutter-camera cone and mount. Second that a glass window be sealed in the bottom and the exposures made through this window. With the motor to the rear, little difficulty would be experienced in keeping the window clean. The biggest problem in a sizable window is the pressure that this window would have to stand in a supercharged gondola. The same pressure which is applicable to the camera window is also applicable to the other windows and cabin structure. Insofar as there is a difference of 5.8 pounds pressure between 14,000 and 40,000 feet in elevation, the pressure on a window 10 x 20 inches in size would be 1,160 pounds.

Safety is another consideration. A structural failure in the metal or glass covering of the supercharged gondola which would let out the pressure instantaneously would subject the crew to a change of pressure ailment, commonly called the "bends." But divers and underwater construction workers frequently work under 50 pounds pressure. Whether a quick change of 5.8 pounds would be serious or not is a debatable question.

A NEW TYPE PLANE

By explaining the many features of the new Abrams Explorer, I can best point out the many requirements of a mapping plane.

First, the cabin must be supercharged to operate at high altitudes; so the gondola is built cylindrically to stand supercharging. Second, the plane must have a high cruising speed at high altitudes; so we will use a high compression supercharged motor with two-stage supercharging. Next, the plane must have a rapid climb to altitude—this requires a combination of high lift wing, tapered, low wing loading, and a high power load. Next, we removed the greatest objection to other planes for mapping—"lack of visibility." We made the plane a pusher type, putting the pilot out in front in a plastic-covered gondola. The motor is out behind with all its noise, dirt, gas, grease, and vibration. This one feature has perhaps the greatest appeal to mapping pilots at first sight. This changing
Fig. 1. A ground close up view of the new aerial mapping plane.

Fig. 2. The new aerial mapping plane in flight.
of the motor solved a very important problem. By moving the motor to the rear, it is put close to the center of balance; the torque of the motor is a negligible factor with the line of thrust along the line of drag. The combination of sweep back to the wing with the rudders out of the line of thrust of the propeller makes for inherent stability with power on or power off.

The peculiar sweep back of the wings in the Explorer does several things. First, it makes the plane inherently stable in any angle of flight without having to add dihedral, which would have decreased speed. Second, it puts the wings back out of the way of both pilot and cameraman so that as one flight line is completed and the turn is made to come in on the next flight line, the wing does not obstruct the vision of the pilot or the cameraman as is often the case with a lower or upper wing straight and even with the pilot's seat.

Trimming tabs are provided, as are adjustable stabilizer and landing flaps, and these, together with the three wheel safety undercarriage, permit operation in and out of small rough fields.

In the Explorer, the fuel supply is located on the center of balance so as not to change the normal flight of the plane as the gas supply is depleted.

Thinking of the future, we engineered a plane that might be used in many ways. It would be possible to mount the camera in the Explorer in conjunction with a directional gyro and an artificial horizon or a robot cameraman so that, with a large magazine capacity, only a one-man crew would be necessary to execute a mapping job.

From our own experience, we believe that radio directional finders should be considered as a definite part of a mapping plane's equipment.

Many ideas on navigational aids are evident, and each has its merits and limitations. Our own idea is to use as many as possible, checking one against the other. Automatic, mechanical, or robot pilots will certainly be used in increasing numbers because they allow the pilot a freedom from attention at the controls and an opportunity to study the ground and his instruments.

**FUTURE MAPPING IN THE UNITED STATES**

In considering future mapping work in the United States and the possible outlet for extra work for aerial survey operators, thought should be given to high altitude photography in the more developed agricultural areas in the United States. It would be possible to map these areas from altitudes from 36,000 to 40,000 feet with wide-angle lens and produce a type of map which would be transposed into maps suitable for many purposes. It would be possible, from high altitudes with specially designed airplanes and special cameras, to map or
remap large areas of hundreds of thousands of square miles at a price of something less than $1.00 per square mile. This would offer an interesting and perhaps lucrative outlet for aerial survey operators in the future.

In considering the western third of the United States, the level of which is from 6,000 to 14,000 feet high, consideration must also be given to airplanes which could map this area from still higher altitudes than in the past. The land itself has a limited value. For that reason, maps of a large scale at low altitudes are not economical. If the area could be mapped from an elevation of 36,000 to 40,000 feet at a low price, then the mapping of this area could probably be considered by government agencies.

In the same way, the rough, undeveloped, and higher land of the United States needs mapping. There is also a similar need for mapping in the wild and undeveloped land of some other countries. High altitude photographs of these areas are a commercial possibility and could be done at a very low price if the work could be done at such an altitude that the cost per square mile could be reduced.

HIGH VS. LOW ALTITUDE MAPPING

Considering the economics of high-altitude mapping with a wide-angle lens against the cost of mapping at lower altitudes with multiple-lens cameras, the advantage is in favor of high-altitude airplanes especially equipped for this work. It is my belief that airplanes for high-altitude work can be built at a price approximately equal to the price of multiple lens cameras. This being the case, more work could be done in the air and less work would have to be done in the laboratory in transforming photographs made with a multiple-lens camera. Thus, the economies and speed of performance in high-altitude mapping are greater than the economies which might be effected with multiple-lens cameras, which have certain disadvantages.

Another factor which should be given consideration in aircraft for mapping purposes is the making of photographs at low altitudes for photogrammetric work. The European school of thought seems to be that low-altitude photographs made from slow moving airplanes are desirable for photogrammetric work. If this is so it means that the flight lines will have to lie closer together and the flying will have to be done with a greater degree of accuracy than has heretofore been possible when good visibility was not within the limits of the type of airplanes used. In low-altitude, large-scale mapping for photogrammetric work, it is the consensus of opinion that the flying should not be done at a speed of more than sixty miles an hour. This requires an airplane for a particular purpose, and it is our belief that an airplane with a wide range of speed of
from sixty to more than two hundred miles per hour is necessary if it is to be universally used.

In low-altitude photographs, 100% forward and downward visibility is also very necessary, as in this type of work the flight lines are generally short and one has to pick up known ground objects of equal distance apart to be able to fly these lines precisely and very accurately.

In Canada I find a very interesting application of flying to mapping. This is in general called “sketch mapping,” and the procedure is to fly over a given territory, allowing the engineer in the plane to take a look at the ground and then draft up sketch maps as he flies along. This principle has been applied to a large extent in Canada. In a pusher-type airplane like the Explorer, the engineer or sketcher doing the mapping could change places with the pilot and, by sitting in front with the pilot in the rear, much time would be saved in turning around to see the country or in time checking the various distances.

Another system of mapping in Canada is to use three cameras at an oblique angle and then transform these pictures into planimetric maps. The Explorer would adapt itself well to this purpose. In fact, considerable study was given to this one subject alone. Three oblique cameras could be mounted in the nose of the plane, giving the operator excellent visibility, and with the pilot then in the rear, full knowledge of each other’s action would help out considerably in speeding up a project.

CAMERA TYPES

Considering the many types of cameras which are now being built abroad, we find each of these used to serve a particular type of procedure, and so thought has been given to provide the best airplane for each.

The cameras employing an extra-horizon type of camera for showing the angle of the camera in relation to the earth’s surface have considerable difficulty in finding room to get all of the accessories down through the floor of the average plane so that the camera proper and the horizon camera are below the outer covering of the plane. In the Explorer, they are easily mounted because there are no subflooring, wires, or structural members that would be in the way, and the camera mount is on the outer skin of the gondola with nothing in the way. The horizon camera must also be in the clear. In most planes the wheels, the motor, or the tail is in the way. In the three-wheeled Explorer, clear view may be had to either side or to the rear, which is more than sufficient.

Operators and manufacturers of several types of stereoscopic cameras in Europe have experienced considerable difficulty in mounting their cameras in airplanes. Some of these cameras have a fixed angle and some are arranged so that
they are a single camera in a special mount, first shooting one picture forward in line of flight and then shooting one to the rear. In this way, wide angles are obtained for photogrammetric work. In some planes this requires that the complete camera be lowered below the plane. Careful study was made; and, without any changes, these stereoscopic cameras can be easily mounted in the floor of the *Explorer* with ample angular clearance to accommodate the wide angle or stereoscopic camera installation.

The camera in a mapping plane is as much a part of its equipment group as motor or propeller. Therefore, the camera should be picked for the plane and the plane picked for the camera. In 100-miles-per-hour planes, 100-shot magazines might be sufficient; in 240-miles-per-hour planes, cameras should not be considered that have less than 600 shots of full-size film which takes the full covering power of the lens. It takes time to load an aerial camera, and at high speed it is practically impossible to change removable magazines in line of flight. Therefore, in making one turn around to load film or change a magazine some time is lost; maybe five minutes, maybe ten, but let's take the minimum in figuring a saving. In five minutes the plane goes down the flight line 20 miles, and standard specifications being for a flight line two miles wide, this makes forty square miles. Multiply this by, say, six changes per day, and you could have flown or mapped an additional 240 square miles; in dollars and cents at $2.50 per mile, you either have or have not mapped the extra $600.00 worth, depending upon the camera used.

Military people interested in the science of aerial photography for military purposes advance several rather interesting ideas which could be used in commercial or other government work. The first of these is a fully automatic camera mounted in a plane, the plane's flight to be radio-controlled from the ground. In this way, the life of a man would not be jeopardized in wartime as photographs are made in enemy territory. If this can be used successfully in military work, and it is my understanding that it has been, then it might be good for commercial aerial survey operators to use the same system, directing their planes by radio from the ground and mapping straight and direct lines through the air with radio-controlled planes. Cameras could be operated by robot cameramen, and there might be the advantage of economy in such operation. It might even be possible to send planes to still higher altitudes than has ever been considered because motors could be produced which would send airplanes higher into the stratosphere than man could probably work.

Another thought along the line of how a mapping plane might be used is that we should give consideration to television and its application to commercial work. It might be possible to put a television scanner in the *Explorer*, let this airplane
ascend to a high altitude, point the scanning screen vertically at the earth’s surface, then take off the recordings of the scanning screen by television back in the laboratory, making negatives or maps directly from the television receiver. Certain tests have been made along this line whereby the airplane flew above a given scene and made the picture. This picture was then transmitted by television to the ground, picked up in the laboratory, and produced for military purposes. These several angles offer interesting possibilities, and to take the best advantage of all of them, planes especially designed for this work should be used.