as the feathers themselves have been changed in the process of freezing the bird. Another criticism of the frozen bird technique lies in the fact that the bird uses his wing muscles even in gliding flight as a means of control. This is necessary since the bird possesses little or no inherent aerodynamic stability except possibly along the body in roll. In yaw and to a lesser extent, in pitch, the bird with fixed geometry appears to have neutral or negative stability. In other words, the flight of a bird is stabilized by minute involuntary control deflections. This is similar to the process of walking of man in his erect posture.

Another feature of the bird's aerodynamics is the porosity of the feathers. Whether this feature plays an important role in the aerodynamics of the bird or not, is not yet established. Victor Loughheed is reported to have measured the porosity of the bird's feathers, finding the porosity ten times greater in the downward direction than in the direction up through the feathers of the wing.

On some birds, in addition to the usual features of the feathers, flexibility, mobility, and porosity, there is also a toothed leading edge. This is true particularly on the owls which must fly silently and stealthfully upon their prey in the field. Graham (ref. 5) ascribes to this toothed leading edge an ability to reduce the velocity of the flow over the wing. This may be so, but if the flow loses too much velocity near the leading edge, the wing will not develop as high a lift with a toothed leading edge as without. This means that the bird would have to fly faster with a toothed leading edge than with the smooth. Thus, the noise would not be essentially reduced. Yet what the owl does is fly silently.

Perhaps we might speculate on the function of the toothed leading edge by drawing on an analogy. If a piece of wire of cylindrical form about 3 mm. in diameter and a meter long is swung through the air in a rotating motion similar to a propeller, a distinct tone similar to a singing telephone wire is emitted. Now, if instead of a single cylindrical wire, two wires of 1.5 mm. diameter are twisted together in a tight spiral, and then spun, the noise level is much lower in intensity and in frequency. In fact, only the free end emits a noise.

From the foregoing experiment, we might say that the toothed leading edge behaves the same way the twisted wire did, i.e., in a manner to reduce the vortex noise emitted by the flow leaving the wing. However, remember that this is merely a hypothesis and not absolute proof of the function of the toothed leading edge of owls.

Since the bird possesses little or no inherent stability in pitch, the question of the function of the tail comes before us. In general, the tail is used as a landing aid similar to the flap on an airplane. Photographs show clearly that the tail of most birds fans out to increase the lifting area just before touchdown, and is folded during gliding flight.

At the same time, during the landing, it will be seen that the alula or false feather, representing the thumb of our hand, opens in order to increase the lifting power of the wing. This same alula is used as a lateral control for initiating rapid turns.

The reader might wish to try a simple experiment which illustrates the function of the alula. If while driving at about 50 mph, one puts his hand out of a car window with the hand cupped slightly and at a positive angle to the wind, he can by simply moving his thumb up or down, cause a large change in the lifting force his arm experiences. This is how the bird applies control in roll about his longitudinal body axis.

Having shown in figure 2, that windtunnel tests of birds are fraught with possible large errors, we are forced to look for new means of determining the aerodynamic properties of birds.

About 1890-1900, S. P. Langley, then director of the Smithsonian Institute, attempted to determine the flight characteristics of buzzards in the neighborhood of Washington by photographing the birds with two telephoto cameras, arranged stereoscopically. Such a technique would have certainly determined the geometry of the bird while airborne, but it would not have determined the energy losses unless a time lapse method were used together with triangulation by double theodolite methods.

In view of the difficulty of ground based techniques using wild birds, the author and George Carter in 1945 started an experiment in which a young wild buzzard would be trained to carry a small recording barograph and anemograph attached to the belly of the bird. The bird was trained successfully to do his job using a mock-up of the recording instrument which was to weigh 30 grams and have dimensions 2x3x5 centimeters. However, before the actual measurements could be made, the bird died of an intestinal stop-

Fig. 5. Research sailplane for bird flight.