compensated by muscle power for the black buzzard in level flapping flight. The minimum power required to maintain level flight is 0.019 HP. For this bird, which weighs 2.3 kilograms, this results in a power loading of 122 kilograms per horsepower. A rough value of the capability of muscles to put out continuous power is one horsepower for 50 kilograms of muscle.

The value of 122 kilograms per horsepower then implies that 42% of the bird's weight must be attributed to flight muscles. If, then at least 42% of the black buzzard's weight were not in the form of flapping muscles, we could conclude that this buzzard could not maintain continuous level flight without help either from up-currents or from dynamic soaring, which consists of extracting energy from the fluctuations in the wind.

In order to compare the above discussed free flight method for determining the aerodynamics of a bird in gliding flight with windtunnel measurements, the data of figure 6 has been transformed into a linearized drag polar, figure 8. In this illustration are shown the drag polars of the black buzzard in the two modes of gliding flight and windtunnel data for the laughing gull, the cheel (Pariah Kite), and the Alsatian Swift. The same conclusion as was drawn from the single laughing gull measurement is born out by the duplicity of the complete polars of the black buzzard, namely, windtunnel measurements of models of birds can not yield valid information concerning the aerodynamic properties of birds in natural flight. For this reason, progress in understanding the more difficult phases of flapping flight will only be possible when theory can be supported by flight measurements made under natural conditions. In general, the measurements made in windtunnels tend toward ascribing to the bird much higher energy losses than he actually possesses. For this reason, any biophysical conclusions would lead to absurdities if based on windtunnel measurements.

However, the comparison flight method is not without some criticism at the present state of its art. Since the measurements with wild birds had to be made in the middle of the day when birds were soaring, i.e., in a turbulent environment, one cannot absolutely say that the black buzzard possessed the very low drag coefficient which was measured. We say that either he possesses this low drag coefficient, or else he must be utilizing a source of energy which the comparison sailplane was not. The only possibility for such energy extraction lies in dynamic soaring. However, we do have rather positive evidence that the lowest measured drag values are valid for the high speed points on the speed polars of figure 6, which were obtained near sunset when the air was quite smooth during a glide to roost of a black buzzard.

Nevertheless, there cannot but be some doubt about the validity of data taken in turbulent air. For this reason, a measurement made during the early hours of the morning when the air is very still suggests itself. For this test, several wild captured buzzards would be carried aloft in a two-seater sailplane. On tow, behind the same towplane, would be the measuring sailplane, a light, maneuverable design, fitted with radio communication equipment. After the two sailplanes reach an altitude of 1500 meters, they will release from the towplane, which descends to the airport. The bird-carrying two-seater moves ahead of the measuring sailplane headed toward the airport where the birds have been cooped. On a signal from the measuring sailplane, the bird handler releases a bird from the two-seater by dropping him out in an open ended bag to which is attached a line. At the end of the line, the bird falls out of the bag, head first, and will start gliding toward his coop. Whether every bird will cooperate in this manner is yet to be determined. However, if the birds merely glide in any direction, useful data can be obtained, for the measuring sailplane is capable of landing in any small field and can be dissembled for retrieve to its base by trailer.*

During the glide of the bird, the measuring sailplane will take data in the same manner as described for the comparison method.

The precision of this method should be much better, for in this case, both the bird and the sailplane will be flying in smooth air, that in which the sailplane has been calibrated.

The results of these measurements in still air should either confirm the measurements given in figure 6, or perhaps in certain flight regimes, especially at the lower speeds with slotted tips open, there will be a disparity. If the difference is sig-

*Bird flight research following this concept presently is being conducted by Professors F. D. Farrar, Jr., and C. E. Farrell, of Vanderbilt University, under National Science Foundation Sponsorship.

Fig. 8. Linearized drag polar of black buzzard, laughing gull, Alsatian swift and cheel.

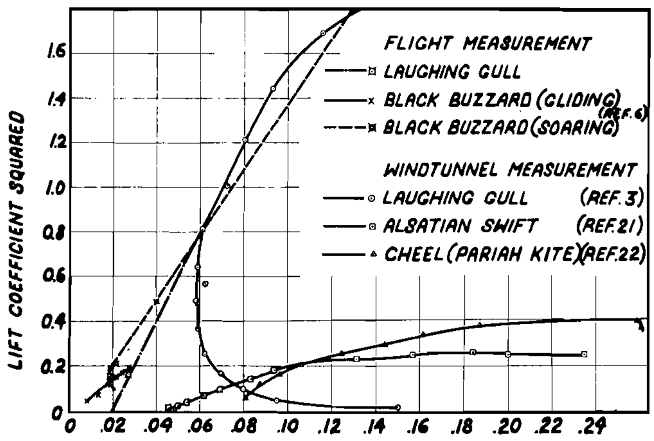

Fig. 9. Skin friction curves plotted against mean Reynolds number for the black buzzard, a high-performance sailplane and a high-performance twin-engined airplane.