flat shore, the increase in friction between the ground and air retards the lower strata of air with the result that the boundary layer thickens and this layer of slowly moving air acts as a solid boundary, diverting the general flow over it. Gulls make frequent use of this declivity source along shorelines. The same effect can occur in somewhat weaker form when wind moving over relatively smooth land suddenly encounters rough or forested terrain.

In order to have declivity currents of sufficient strength to support soaring, it is necessary to have strong winds and/or very large obstructions. In addition, the location of these obstacles is fixed so that declivity soaring flight is necessarily restricted to their immediate vicinity and to such times as the wind strength permits. Obviously, such restrictions cannot be tolerated by soaring birds whose primary flight mission is to cover large land areas in search of food with daily regularity, and so we find but little practical use being made of declivity currents by birds. For sailplanes, however, declivity soaring is still one of the most frequently used forms. Certainly it was the first form to be understood and exploited by man. Here we have an example of a powerful source of energy being available but because of its severe practical limitations is little used by birds, even though they are much better equipped to use it than sailplanes (i. e. birds can vary their wing loading at will and hence can "hill soar" through a much greater range of the horizontal wind velocities than can a sailplane with fixed loading). Except in regions of large, numerous mountains the altitudes attainable by declivity soaring are so low that making distance flights by gliding from source to source is impossible. Hence declivity soaring is of little use to birds because of practical restraints. By the same token, declivity soaring sadly restricts man's soaring accomplishments except in limited mountainous regions, its primary value being to power the now rather pointless declivity endurance flights. Still, due to the ease and certainty of finding and using declivity currents, most sailplanes are designed solely to meet the requirements of declivity soaring. Since, for their existence, birds are required by nature to be a most practical machine, and since they make little use of what has long been soaring man's most valuable energy source, it appears that there must exist yet another source of far more practical value than declivity currents.

We are left then with the thermal currents. Thermals occur when surface layers of air become so warmed or moisture laden by contact with the sun-heated earth that they are less dense than the layers above, and being in a state of instability tend to overturn, thus setting up buoyant convections in the atmosphere. Obviously the formation of these convections depends primarily on the presence of sufficient sunshine and thus their distribution is universal, covering all land areas, mountainous as well as flat. Here indeed is an ideal source of practical soaring power. It is because of their ability to efficiently exploit the ever-present thermal currents that birds are able to accomplish soaring over the broad flat plains in a form equal and usually superior to that observed in mountainous country where declivities are usually present. Actually, it is interesting to note that even in mountainous country thermal soaring always takes preference over declivity flight.* This is not surprising of course as hills are excellent thermal producers. It is indeed an inspiring sight to watch a group of vultures circle to great altitudes on motionless wings, using the invisible thermal power of the air. The sight is even more inspiring when we consider that our best sailplanes cannot begin to match these performances which are practiced with daily regularity over the extensive plains of the southern and central states. One must indeed inquire as to why these birds are so efficient, and as to what man must do so that his sailplanes may approach their performance. This inquiry has been made. The answers will form the remainder of this paper. This brief consideration of the forms of natural soaring is a condensation of the results gained from an extensive investigation by the author into the mechanics of natural soaring.** For those interested in the factual description of natural soaring, the work of Hankin* is highly recommended.

The preceding results indicate that our primary effort in soaring research, at least in this country, should be aimed at obtaining a better knowledge and exploitation of buoyant convections. They alone appear to offer the possibility of greatly extending the range and practicability of soaring in this country. We are fortunate indeed that our geographical location guarantees us good thermal conditions through most of the year; even in the far north, summer thermals are abundant. When the certainty and efficiency of sailplane flight can approach that of soaring birds, the advance of our knowledge of atmospheric phenomena will be greatly accelerated since the sailplane is a most valuable tool for meteorological research. With a certain knowledge of the atmosphere the spread of practical soaring can be rapid.

Outline of the paper.—In the remainder of this paper a quantitative theory of thermal soaring will be developed. The theory, both meteorological and aerodynamic concepts, was originally developed by the author to explain the flight of soaring birds in Georgia thermals. The author's theory of the thermal shell and its approximation by a vortex ring flow was developed some years ago to explain the ability of soaring birds to remain for such long times in finite buoyant convections. Later studies of the fluid dynamic properties of such a system allowed a more quantitative description of the theory. Supporting evidence, both theoretical and experimental, has since come from many sources.

The primary purpose of thermal soaring is to gain or maintain altitude. This requires of course that the sailplane circle within the upcurrent of the thermal as long and as efficiently as possible. Once the altitude has been gained, it may be used to accomplish distance flight or any other task, but this secondary flight phase is not of interest here. We shall in this paper attempt to learn how to design and fly our sailcraft so that their climbing velocity relative to earth will be a maximum for the existing thermal currents; the final design of the craft will of course be a compromise between thermal requirements and those of the secondary flight phase. The presentation will consist of three parts. First, the nature of thermal currents will be briefly investigated and an idealized form developed so that the exact motion of the thermal air relative to the earth becomes known. Then the motion of the sailplane in

* E. H. Hankin: *Animal Flight: A Record of Observations*, Iliffe and Sons, Ltd., London, 1913.

** C. D. Cone, Jr.: "On the Thermal Soaring of Birds," submitted for publication in the *Condor*, July, 1960.