circling flight relative to still air will be investigated so as to determine the effects of the aerodynamic properties of the craft on the circling motion. Finally the motion of the craft relative to the earth will be obtained as a function of its aerodynamic characteristics by superposing the motion of the craft relative to the air on the motion of the air in the thermal relative to the earth. The results will be briefly analyzed to give us a useful picture of the interrelations and effects of the various aerodynamic parameters on the thermal soaring ability of sailplanes, and hence an indication of the design criteria necessary for maximum thermal utilization.

THEORY OF BUOYANT CONVECTIONS

For maximum utilization of thermal energy for soaring flight, a quantitative knowledge of thermal air motions is required. Although the understanding of buoyant convections is far from complete, theoretical and experimental work has reached the point where some useful applications to soaring can be made. The overall theory of the subject is too extensive and complex to discuss here, but it is necessary to develop at least the more important concepts. The results will be sufficient to demonstrate the possibilities of the application of meteorological data to sailplane design and to point out some critical unknowns which require meteorological research.

Origin of buoyant convections.—The ultimate origin of all naturally occurring buoyant convections in the atmosphere is sunshine. Thus we may say that in thermal soaring we are literally flying on solar power. (Actually, every form of soaring ultimately depends on solar energy.) The process by which this incident radiation is transformed to power thermal soaring flight is a most complex but fascinating phenomenon. It is not nearly so simple as the popular "warm air column" concept might suggest. Let us consider the initial phase of thermal formation.

As the morning sun shines upon the earth, the energy is transformed to heat which initially raises the ground temperature. If the ground is moist, much of the heat goes into the evaporation of water to vapor. The same is true on forested terrain where the heat vaporizes the water released by foliage transpiration. On dry soil and on rock surfaces the sunshine causes a rapid increase in the temperature up to the point where the rate of heat transfer to the surrounding air plus the outgoing radiation reaches an equilibrium. As the day progresses and the intensity of sunshine increases, increasing amounts of energy are continuously transferred to the air layer near the ground in the form of heat and water vapor. The warm air-water vapor mixture is less dense than the cooler, drier air above it and, due to the buoyancy forces existing, an unstable equilibrium is set up. Under the intense surface heating the equilibrium becomes more and more unstable. In general, the air is slowly drifting over the land surface so that the warm air layer is not stationary but moving horizontally. Finally, due to some triggering action such as a local overheating or disturbance by an obstruction, the local equilibrium is upset and the warm air begins to penetrate into the colder air above. The initial protuberance thus developed grows rapidly as the warm air of the surface layer flows into it.

The ensuing convection which develops from this initial protuberance can have either of two forms depending upon the existing conditions. It can form into either a continuous column or a discrete air mass. If there is a large supply of warm air and the triggering takes place continuously at a fixed point on the ground there will be a more or less continuous column of buoyant air streaming from the point. This fixed source can form at an obstruction where the warm air is initially forced upward by the obstruction and continues its ascent due to its buoyancy. An example of this is a ridge or hill on or at the edge of a large plain, the air being continuously heated as it flows over the plain towards the rising column at the ridge. Another example of a fixed source is a sun-facing slope or cliff which receives more sunlight per unit area than flat ground at certain times of the day and is thus able to supply a continuous flow of warm air for a short period of time. Usually, however, it is rare that a truly continuous column forms for this would require almost completely calm air conditions. Instead, the column of heated air from the source constantly breaks up into discrete masses which are then carried along by the wind.

In general, the source of buoyant air is neither fixed nor continuous. Local overheatings and disturbances in the warm air blanket are occurring simultaneously at many points as it moves along, so that protuberances are forming at many random points at any given time. Thus the warm air supply for any one protuberance is limited and the convection which forms can contain only a limited mass of buoyant air. This discrete mass forms a free thermal which floats off with the wind as it rises, much like a free balloon. Once the convection has formed, cooler air flows in to take the place of the warm, and the heating process begins over again. On a warm day the earth's surface looks exactly like the bottom of a kettle of gently boiling water with the buoyant air masses rising from many points exactly like the vapor bubbles, and for exactly the same reasons.

Direct sunshine is a sufficient but not absolutely necessary condition for the local formation of buoyant convections. Even in very cloudy weather powerful thermals can form if the atmospheric lapse rate is superadiabatic. However, the best thermal soaring weather is always coincident with direct sunshine. It should be noted that it is only the density *difference* that is important in establishing buoyant convections, not the absolute conditions of the atmosphere. Thus even on a cold day powerful thermals can arise if the surface heating (sunlight) is great enough. However, very cold air is usually an indication of a low sunshine intensity so that fewer thermals are naturally available in winter.

Thus we see that most thermals constist of discrete masses of buoyant air and not continuous columns. Once they have formed, they are completely free of any ground connection and drift with the prevailing wind. Until recently, the belief has been that thermals were merely continuous columns of warm air rising from fixed spots on the ground. This is understandable since the location and utilization of these fixed sources by sailplanes is a relatively simple matter. They merely circle in a thermal column from such a source until they pass out of it and then glide upwind to the source to repeat the procedure. While it is true that some locations exist where the terrain is highly favorable to production of column convections.