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THE FLIGHT OF THE BUMBLEBEE

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This article was published in "Investigación y Ciencia" ("Scientific American"), in Spanish language, February 1986, and is transcribed in full here below, together with the corresponding illustration (see Fig.):

SIKORSKY, the famous aeronautic designer, ordered this notice to be hung up in the lobby of his technical office: "the bumblebee, according to our engineers' calculations, cannot fly at all, but the bumblebee does not know this and flies". There are quite a number of studies about insect flight and all of them come up against enormous difficulties when they try to explain the mechanisms of lift through the dynamics of stationary fluids. Let us take a look at some examples.

TORKEL WEISS-FOGH wrote eleven years ago (in 1975) in *Scientific American* that: "the most important aspect (lift) of these insects and other flying creatures depends largely on aerodynamic effects which are not stationary, and hitherto unknown, which for them are useful and not a hindrance as they would be for man-made aeroplanes". In another study, on the subject of *Haplothrips verbasci,* ARNOLD M. KUETHE said something similar: "Ignorance of the details about the mechanism of flight, at such a low number of REYNOLDS, shows the need for extensive observations during flight in order to determine the movement of the wing-bars and of the cilia and, likewise, the need to penetrate more deeply in the study of these details using the electronic microscope, and also measurements designed to determine the properties of the group of cilia..."
We could add a great deal more evidence. The reader will find the problem dealt with clearly in the article by JOEL G. KINGSOLVER published in these same pages about the engineering of butterflies (October 1985). Amongst other things he described the difficulties found in complex insect flight, many of them insuperable, having recourse once more to TORKEL WEIS-FOGH's hypotheses.

For some years I have been investigating, empirically and theoretically, a new approach to dynamics of which Classical Dynamics would be a restricted part. Amongst other things it opens up the possibility that propulsion and lift exist even in the absence of atmosphere. How can insect flight be explained, from the dynamic point of view? Evidently it is not reasonable in the framework of Newtonian dynamics in which the conservation of lineal momentum, in an isolated system, excludes this type of lift and propulsion.

In the field of cosmology the insufficiencies of Newtonian mechanical theories in their fundamental axioms were detected many years ago. Thus, the "first principle" asserts that an isolated material point (or system) follows a straight trajectory with a constant velocity; but the movement must be related to some inertial coordinated axes, external to the particle (or system) in question, which means that the isolation which is postulated is questionable, since it leads us to the contradiction that an isolated system has the property of not being isolated. This is the "weakest point of the magnificent edifice of Newtonian mechanics" (P. HOENEN, 1948). This First Principle must be rectified by asserting that there are no inertially isolated systems.

With this new starting point, together with the axiom of energy conservation, this new dynamics began to take form beginning with the simplest case in which the potential energy is conservative, to generalize it, in a second step, to the non-conservative case. It leads us to the surprising result that in addition to the Newtonian forces of inertia, which only consist of the accelerations of particles and their respective masses, there are in fact other forces of inertia –hitherto unknown– which also include the velocity of particles, whose mass may behave as non-constant in the non-conservative case. These forces are isomorphic with "LORENTZ's forces" of electromagnetism, whose origin is purely empirical.

In the conservative case, the particle is affected by only one other force in addition to the classical ones: we have called it the *force of drag,* which is superimposed on the Newtonian one and is normal to the trajectory; it has the quality of changing sign when the physical point reverses the sense in which it is moving on the trajectory. We have an example in HALLEY's comet, which could be asymmetric when it passes through the perihelion, that is to say, the in going arc might not be identical to the outgoing one.

Passing on to empirical observation, we can use the bumblebee, *Bombus terrestris*, as an experimental source. The equipment I used to observe the "abnormal" lift of the insect in a vacuum consisted of a vacuum pump, a glass container, a triple stopcock and a pressure gauge (see the adjoining illustration). The vacuum pump must be one of the kind known as "water trunk", used as a filter in chemistry laboratories. No other kind of pump must be used for a very simple reason: it is vital to maintain the partial pressure of the water vapour at room temperature, so that the insect does not swell up or become otherwise deformed, as would happen if we used a different type of pump, even if the vacuum obtained were greater. Moreover, it is so quick and effective that the insect remains active in the vacuum for a maximum of one or two minutes. At a room temperature of *15 degrees* CELSIUS, a vacuum of *10 tor (13 mb)* is obtained, which compared with the normal value of atmospheric pressure *(1013 mb)* implies a vacuum of *98.7%.*

A transparent glass container of *1000 cubic centimetres* is used to hold the insect, closed hermetically with a rubber stopper and an outlet in the side to which the pressure tube, also rubber, is attached in order to cause the vacuum at the right moment. Larger containers should not be used in order for the emptying time to be minimal –about ten seconds– thereby allowing a maximum period of observation. The insect is introduced through the opening in the top which is then hermetically sealed.

Valves, or triple stopcocks, of this kind are very simple and cheap, made of glass; it is inserted into the pressure tube, to connect the vacuum pump to the glass container. This valve enables us to re-establish atmospheric pressure in the container, after having produced the vacuum, without it being necessary to disconnect the pump, and to maintain the vacuum indefinitely once it has been obtained. It also serves to check the level of vacuum which has been produced, by means of a pressure gauge. On the question of low pressure gauges, the mercury ones are very reliable and also digital precision pressure gauges.

It is well known that insects activate their flight capacity if they reach a suitable temperature. (It would be a good idea to place a "flexi" lamp near the container for illumination and also to provide sufficient heat for radiation.)

The observational results are surprising: for one or two minutes the insect continues flying, or takes off in flight, without any perceptible difference from flight at normal atmospheric pressure, even when hovering. The insect's legs are in the habitual position for flight, that is, gathered up and folded backwards.

The wing beat frequency is a characteristic of each insect which varies between very narrow limits in each species: around *300 hertz* for the bumblebee and *150 hertz* for the fly. Lift has an approximately lineal variation with the fluid density, so that flight in these conditions if we wish to explain it in terms of aerodynamics– would mean that the insect is capable of lifting a weight which is more than a hundred times greater than its own in normal atmospheric pressure; which does not seem scientifically acceptable.

In the case of insect flight the problem is generally not conservative and in this New Dynamics –which we have presented generically at the beginning of this article– there appear forces, which were hitherto unknown and responsible for lift and propulsion (without air being needed) which allow the empirical fact which we are putting forward to be explained. This is because in this new dynamic approach the laws of conservation of lineal momentum and angular momentum do not generally apply.

Classical dynamics is still perfectly applicable to those cases in which the system behaves *as if it were* inertially isolated, because of symmetries, zero tangential acceleration, circular orbit, etc., or else the new forces are negligible with regard to those which result exclusively from the masses and accelerations of the particles.

Thermodynamic *irreversibility*, the "strange and troublesome second principle" (J. MERLEAU-PONTY) which is incompatible with classical dynamics (MISRA-POINCARE theorem), is clearly shown to be corollary to the new dynamic approach, as is the particle-wave dualism. MAXWELL's equations of electromagnetics are deduced as a particular limit case of this ND. It must be noted that D. W. SCIAMA in 1953, FELIX TISSERAND eighty years earlier and, more recently, BRANS and DICKE all attempted an inverse process: to construct a theory of gravitation which was isomorphic with MAXWELL's electromagnetism.

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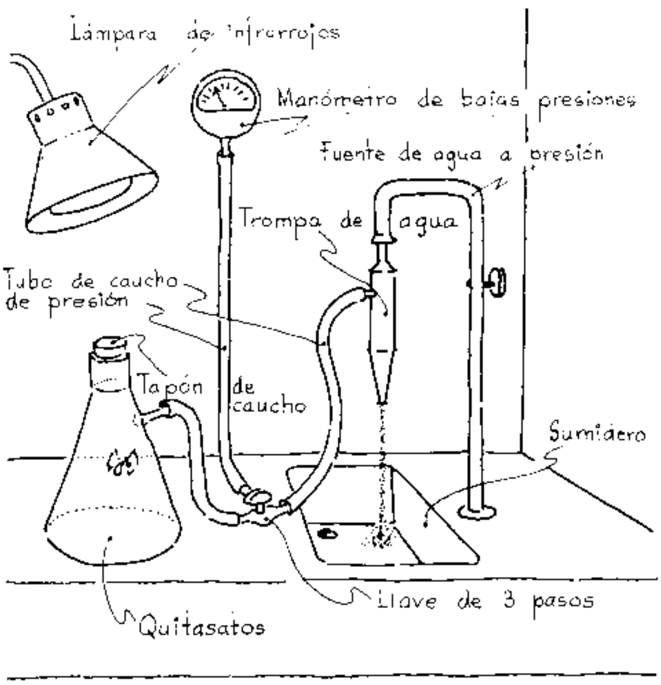

Vuelo del insecto en el vacío. Montaje del experimento.

(Figure attached to the text)

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