Concept of a Lenticular Hybrid Airship Using Hydrogen for Multiple Operation Modes

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1. Introduction

Already the ancient Greeks recognized the disk being an efficient projectile which improved the throwing range in comparison with an equivalent ball by virtue of its particular shape, a shape which may be described as a flattened ellipsoid of rotation or – aerodynamically – a lifting body with a lift/drag ratio in the order of ten. For this reason the disk became also a popular piece of sports equipment.

The ideal discus, however, succeeds only if you put this projectile into rotation about its main axis by means of an additional impulse during launch in order to obtain an effective gyroscopic stabilization of the flight path due to its symmetry of rotation. One should be reminded at this place whenever a lenticular shape is considered as a potential configuration for an airship, the aerodynamic lift will always play a major role during flight in one respect or the other!

2. State oft the Art

In the field of heavier-than-air development, the circular wing plan view had aroused the interest of aircraft designers, because those wings are stall-free even at high angles of attack. In the 1930ies Charles Zimmerman designed such an aircraft which provided at that time high airspeed, but could take off and land at extreme low speed. For these properties, this "Flying Pancake" was ideally suited for aircraft carriers.

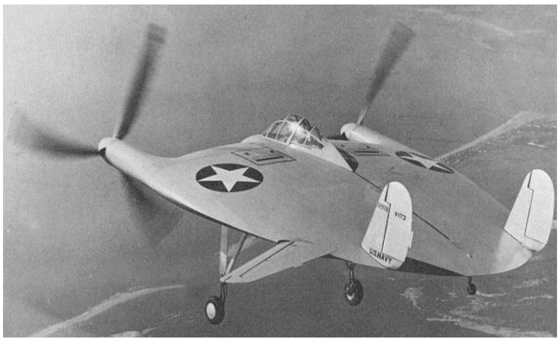

Fig. 1: The "Flying Pancake" by Ch. Zimmerman, Prototype Vought V-173 (1942)

One may recognize the approximate circular plan view of this flying wing design, but suspects also the difficulties concerning the required location of the center of gravity in order to provide the necessary flight mechanical stability. This development was terminated on account of the rapid development of jet combat planes.

At the beginning of this century the concept of a lenticular hybrid airship, the "AirFerry" (Fig.2), was developed by an Ottobrunn engineering team as a multipurpose carrier with VTOL potential by means of a quadruplet of vectored thrust propeller units (Fig. 3)

Fig. 2: Artist Conception of an AirFerry Carrier

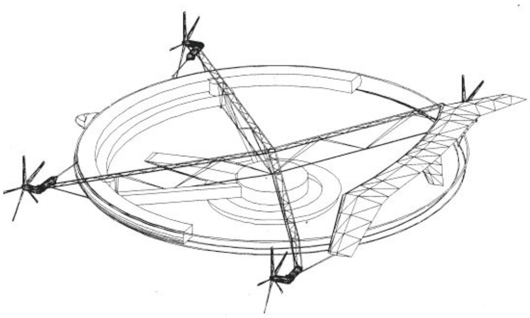

Fig.3: Quadruplet Configuration of Tiltable Propellers (AirFerry Concept)

In Fig.3 is also indicated the additional necessary rear wing which is foreseen to overcome the inherent aeromechanical longitudinal instability of the lenticular planform and had been thoroughly tested in the wind tunnel. This wing generates additional lift, but also increases the deadweight and the additional costs and mechanical interfaces, especially whenever larger scales of carriers are under consideration.

In the following it will be attempted to develop a concept which may be considered a step in the right direction on the ground of the broad spectrum of operational potentials and adaptability to future-oriented technologies.

3. System Concept

3.1 Aspects of Light Construction Technology for a Flattened Ellipsoid of Rotation

A sectional view through a flattened ellipsoid of rotation can be simplified by means of two characteristic radii; i.e. the large all covering radius of the cupola and its counterpart of the lower half and, additionally, the smaller radius of the peripheral ring structure which, in combination with an inner wall, gives that ring a remarkable stiffness against torsion. This ring structure contains most of the subsystems, while the inner space contains mainly the lifting gas, the ballonets and the cargo provisions. By means of a moderate interior pressure, the over-all structure obtains a considerable stiffness due to the membrane tension. This explains briefly the structural concept of a lenticular airship on account its axial symmetry.

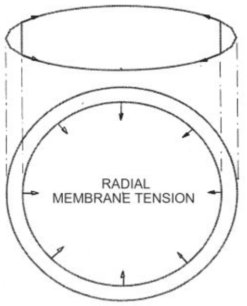

Fig. 3: Axial Symmetric Annular Structure to Counteract the Tensions of the Cupola and Bottom Membranes

Based on the definition of the flight orientation, all essential elements will be installed accordingly, e.g. the propulsion units which are rigidly attached to the torsion-stiff ring structure while the cockpit with all required control and monitoring units will be installed in the bow section of the ring. The remaining subsystems are, equally balanced according to their mass properties, located within the ring.

3.2 Lifting Gas Hydrogen and Ballonet Filling With Inert Exhaust Gas

As a rule only as much as hydrogen will be inflated until it is balanced with the empty weight of the airship; i.e. we create virtually a weightless carrier system according to the onset: **Aerostatic Lift = dead weight !** The remaining volume of the interior will essentially filled with the cargo provisions and the ballonets which – during flight operation – will be permanently flushed with dried and purified exhaust gases. Due to the minimum residual oxygen in the exhaust gas, no combustible or explosive gas mixture will be possible, even in the case minor quantities of hydrogen may penetrate the ballonet hull on account of poreosity.

The degree of inflation, i.e. the ratio of lifting gas/total available volume is a function of the third power the linear dimension of the airship. For instance, a disk of 50 m diameter requires about 100 % inflation with lifting gas; in other words, one could operate this craft only near the ground due to the barometric expansion. At a linear dimension of about 100 m, however, the degree of inflation amounts to merely 55 % corresponding to a pressure height of more than 5000 m, a safe altitude for most weather conditions.

Assuming the concept of a “weightless carrier system”, the useful load will be carried by the aerodynamic lift of the disk and will require an airspeed of about 150 km/h at an altitude of approximately 5000 m in agreement with the data of efficient airships. One may postulate the quadruple equation: **Empty Weight = Aerostatic Lift = Useful Load = Aerodynamic Lift** which constitutes an approximate rule for a hybrid airship. This complies with the rule-of-thumb for carrier planes that the useful load shall be about 50 per cent of take-off weight (= empty weight plus useful load).

3.3 Additional Hydrogen Gas as Fuel and Consequences Regarding the Operational Scenario

If we consider the quadruple equation in the foregoing paragraph in a generalized form, we obtain the relation **Empty Weight + Useful Load = Aerostatic + Aerodynamic Lift** , thus offering subsequent variations of the operational scenarios:

(a) By inflating the airship with additional hydrogen gas, the aerostatic lift will rise, the degree of inflation will increase, but the flight ceiling will be diminished. The positive aspect: the propulsion energy required is reduced. At the same time, the ground pressure of the landing gear will be reduced and – consequently – the take-off and landing velocity.

(b) The additional hydrogen gas can also be used as a pressureless fuel gas, thus producing CO_2-free exhaust gas and increasing the flight ceiling at the same time. For instance, 10,000 Nm^3 hydrogen represent an energy content of 30,000 kWh. A power requirement of about 1000 kW results in 10 hours of continuous operation, assuming an efficiency of 30 per cent.

(c) Finally, at a high degree of inflation and corresponding payload reduction, it is possible to reduce the take-off speed to zero; in other words, the airship performs a vertical balloon launch! The pressure height, however, will be reduced to near zero level until sufficient hydrogen fuel gas has been consumed to gain altitude.

The upshot is that a hybrid airship can for an extended period of time exclusively flown with ecologically desirable and low-priced gaseous hydrogen, whereas the missions can be adapted to the individual take-off and landing conditions. Except for the excellent properties for the use as short-range aircraft, it is for long-range missions suited, as well. With an initial degree of inflation of 90 percent, the ascent phase can be fuelled exclusively with hydrogen. The flight ceiling can be gradually increased due to the hydrogen consumption, until the maximum altitude of more than 5000 m is reached at a distance of 2000 – 3000 km. From there-on low-carbon liquefied natural gas or methane will be used for the remaining flight route.

3.4 Realization of Flight Stability

A practical solution to cope with the longitudinal flight instability would be to suspend the load in a gondola at a proper distance from the hull; in other words, place the center of gravity at a proper distance below the center of the Archimedian buoyancy, thus creating a stabilizing moment. A historical example is given by Santos Dumond's one-man airship; pitch control was simply achieved by moving the pilot back and forth in an elongated gondola.

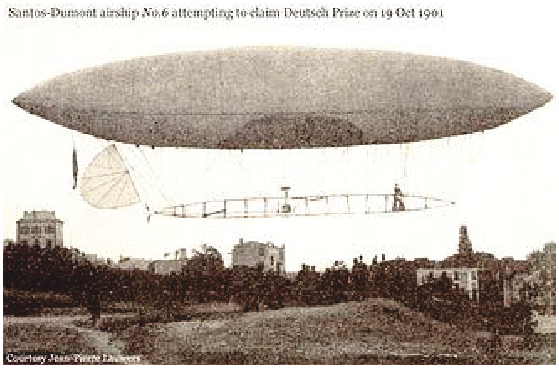

Fig. 4: Pitch Stability and Control by Means of Pilot's Positioning on an Elongated Gondola 1901

Considering a flattened ellipsoid as a circular wing, the aerodynamic center lies about a sixth of the circle's diameter in front of the geometric center of the ellipsoid. Consequently, a strong pitching moment will not allow a stable flight pattern, unless an essential weight will be shifted like Santos Dumond in person at his flight 1901.

In the case of lenticular airship, however, it is necessary to position the load carrying gondola inside of the "aerodynamically clean" hull. Besides it is required to shift the gondola within wide limits alongside, according to the actual positions of the aerodynamic center. This will be done by guide rails on a longitudinal overhead gantry which allow a precise positioning of the gondola at the desired trim location as indicated in Fig.5. This suspension beam, running almost from bow to stern, enables also loading and unloading through the fore and aft cargo doors at the bottom of the hull. The advantage of this interior cargo suspension is obvious, since the conventional heavy cargo floor can be avoided.

In the case of a hybrid airship, the empty weight will be completely compensated by the aerostatic lift, virtually a "weightless carrier system". The magnitude of aerodynamic lift will thus only determined by the useful load which in this case equals about the empty weight of the craft.

The static stability of an lighter-than-air vehicle will be warranted by the positioning of the center of gravity well below the center of Archimedian lift, whereas the dynamic stability of an aircraft demands the c.g. to be located in front of the aerodynamic center. In the case of a lenticular configuration, the aerodynamic center will be always in front of the overall c.g., albeit an static equilibrium could achieved by shifting the suspended load to the position of the aerodynamic center on the x-axis (Fig. 5). This equilibrium is nevertheless dynamically instable, as can be shown in Fig. 6 , because of the aft position of the common c.g. relative to the aerodynamic center.

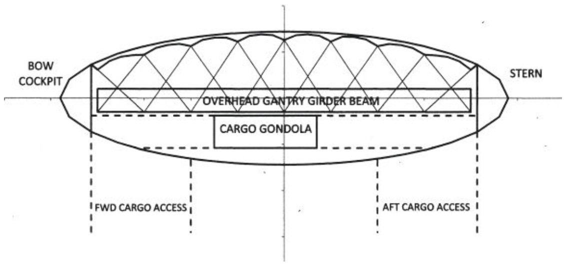

Fig. 5: Interior Suspension of the Gondola on a Longitudinal Traveling Gantry Beam

The bright outlook is the counter-effect of static stability due to the buoyancy of the hybrid airship which is also demonstrated by the pitch simulation in Fig. 6.

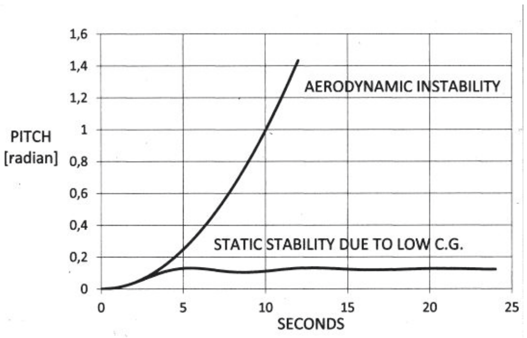

Fig. 6: Aerodynamic Pitch Instability and the Effect of Static Stabilization Due to Buoyancy and c.g. Location

3.5 Trim, Control and Damping

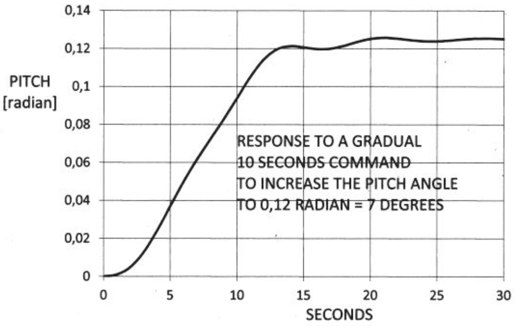

Fig. 7: Pitch Control by Shifting the Suspended Load by 1 meter aft during 10 seconds

Elevator control and trim about the pitch axis will be performed by means of the previously described “Lilienthal-Dumond”-control. Subsequent simulation demonstrates the transition from about zero pitch to 7° (= 0,12 rad) within ten seconds by shifting the suspended load by one meter aft, as can be seen in Fig. 7.

Yaw control may be simply performed by asymmetric thrust of the propulsion units. For roll and pitch damping, classical ballonets are provided using the usual tandem configuration, roll damping will be accomplished by a pair of right/left located ballonets (see Fig. 8).

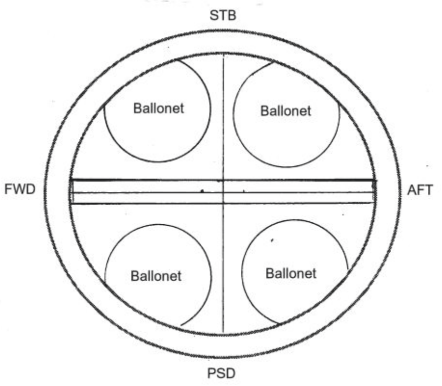

Fig. 8 : Schematic Configuration of Ballonets for Pitch and Roll Trim and Damping

The controlled inflation of the lateral ballonets substitutes in effect the ailerons, due to the lateral shift of the center of aerostatic lift. An induced banking will cause a yaw due to the eccentric location of the c.g. location of the gondola. The effect is similar as with a combined bank-and-yaw control.

The situation changes in the case of gusts; in this case we have to deal with transient effects relative to the mass c.g., while the preceding effects referred to the static balance of forces (weight and lift). Due to the internal slosh damping, the airship reacts like a raw egg when somebody wants to put it into rotation.

3.6 Distribution of Concentrated Loads

The development of non-rigid airships (blimps) as well as rigid airships offers numerous examples, how concentrated loads may be distributed by cables over extended areas.

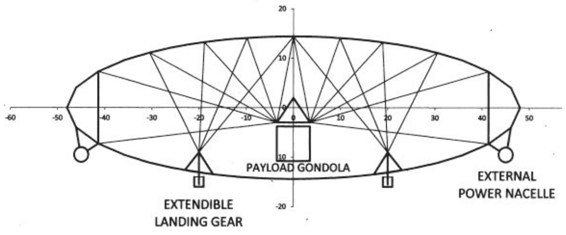

Fig. 9: Cross Section Showing the Suspension of the Longitudinal Gantry Beam and Distribution of the Forces From the Landing Gear

For instance, Fig. 5 shows the suspension of a longitudinal traveling gantry beam in the xz-plane, Fig. 9 the cabling in the yz-plane.

The suspension cable system guaranties the lateral positioning of the longitudinal gantry beam and the payload gondola. The transfer of the cable forces into the hull membrane will be performed via catenaries, as being done in conventional blimps.

The multiple-tandem landing gears are mounted on two parallel longitudinal arched beams within the bottom shell. Due to a moderate internal pressure, the interconnected cables are thus under tension which will be reduced during the landing shock and thus indirectly transferred to the gondola.

The side view Fig. 11 indicates the fore and aft landing gears at the positions of the corresponding wire-spoke bulkheads.

3.7 Propulsion System

3.7.1 Electrically Driven Propeller Nacelles

A total power of ca. 1000 kW will be supplied by a pair of turbine generators as described in the subsequent paragraph.

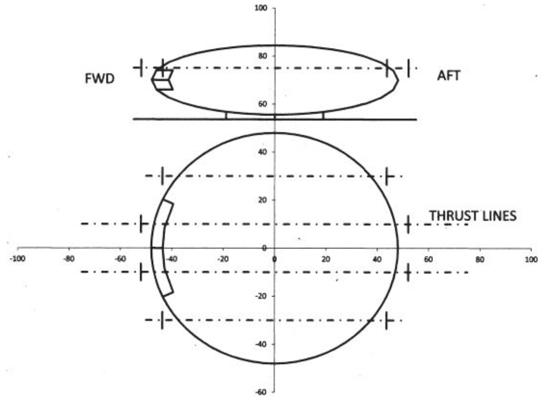

Fig. 10: Sideview and Planview Arrangement of the Electrically Driven Propulsion Units on the Upper Surface

The Fig. 10 shows the configuration of eight electrically driven propulsion units as four tandem configurations, respectively. The reasons for this arrangement are:

- to keep the c.g. of the empty airship at the geometric center of the lenticular configuration,

- to clean the aerodynamic flow across the surface and to blow away potential dust and precipitation off the upper surface.

Each pair of engines are mounted in common elongated nacelles which are integrated in the upper surface.

3.7.2 Generators and Ancillary Systems

The airship is equipped with a pair of laterally mounted external power generator nacelles for reasons of fire safety, as can be seen in Fig. 9 and in Fig. 11.

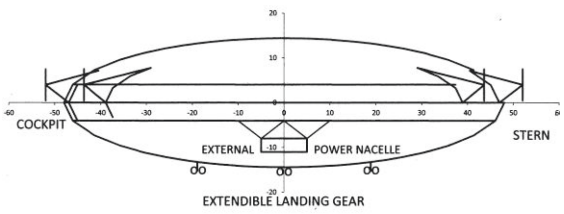

Fig. 11: Side View of the Lenticular Airship Showing the Laterally Suspended Power Generator Nacelles

Each nacelle contains a certified turbine which drives an electric generator for 500 kW. Further equipment is a combination of an exhaust filter and cooler/condenser which channels part of the exhaust gases as an inert gas to all internal places where flammable oxyhydrogen mixtures could be possibly generated.

3.8 Mooring

Due to the axial symmetry of the configuration without aerodynamic surfaces, there is no obvious need for windsock mooring. Circumferentially attached mooring lines can therefore dropped from the rigid ring structure to flush ground anchores.

4. Fire Prevention

Fire prevention methods are based on avoidance of ignitable hydrogen/air mixtures. The following paragraphs describe the main precautions.

4.1 Lightning

In this case the existing aeronautical provisions apply concerning the equalization of electrical potentials of all metallic construction materials on board. Furthermore is the generation of electrostatic electricity – e.g. due to friction – to be avoided by selection of materials.

4.2 Hull Selection

The hull material must provide a high degree of impermeability for hydrogen which will not deteriorate due to stress and ageing beyond a preset limit. Spurious gaseous hydrogen will volatize into the ambient air rather quickly, thus generating no ignitable gas/air mixture.

The hull shall be fireproofed and not ignitable in case of impacting sparks (A metallic membrane should be preferred under this aspect).

4.3 Ballonets

The ballonets will be inflated during operation with purified exhaust gases containing only residual oxygen; thus avoiding ignitable gas mixtures in case of accidental hydrogen invasion. Since permeability and porosity, respectively, increase due to ageing, all ballonets must be equipped by adequate gas sensors. (Same applies for potential gas cells)

All textiles must be provide ample electrical conductivity to avoid voltage differentials.

4.4 Double Wall Textile Separation Insulation

Cockpit and in normal operation accessible spaces must be separated from the hydrogen volume by means of double wall insulation. Same applies for the textile tunnel for the gondola track, extending over the entire length from the bow towards the aft loading doors.

All double isolation walls will be preferred for the ventilation with inert (purified exhaust) gases. At critical locations there are H_2 sensors to be installed.

5. Design Options

5.1 AirFerry Derivative

For preferably VTOL operations a viable option of the previously described concept is conceivable as shown in Fig. 12 which makes use of the rigid outer ring-frame structure of the lenticular design as a basis for the outriggers.

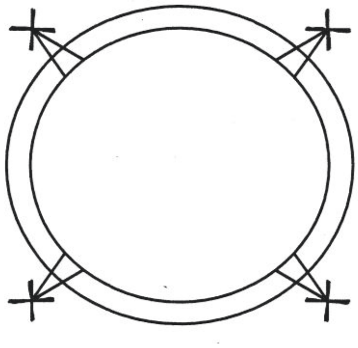

Fig. 12: Outrigger System Integrated With the Basic Rigid Frame Structure of the Lenticular Configuration

The entire configuration appears as an enlarged AirFerry without the stabilizer wing, yet utilizing hydrogen especially as a fuel gas for short-range missions.

5.2 Electrical Power Generation by Fuel Cells

In the course of the further development of fuel cells it is conceivable that power-to-weight ratio may be reduced up to the point where it will become worthwhile to use them as a source of electrical power for airships.

The availability of unpressurized hydrogen gas and liquefied methane as the main fuel sources are self-evident arguments for the future installation of fuel cells instead of turbine/generator combinations.

It is to be expected, however, that the weight-to-power ratio will be still a high one in the future. For the lenticular airship it seems therefore worthwhile to install the fuel cells as a part of the moving payload gondola, thus being an efficient part of the c.g. control system.

6. Summary

A hybrid airship in form a flattened rotation symmetric ellipsoid offers the following advantages:

- Efficient semi-rigid structural concept
- Elimination of extra weight, interfaces and drag penalties on account of external surfaces
- Combined c.g. control and cargo handling system by means of an overhead gantry crane design
- Double utilization of hydrogen as lifting and fuel gas, the latter one without the need for compression and/or liquefaction
- Circumferential mooring independent of wind direction.

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