China's Shanghai Jiao Tong University - Zhiyuan-1 and Tianzhou-1 unmanned research airships

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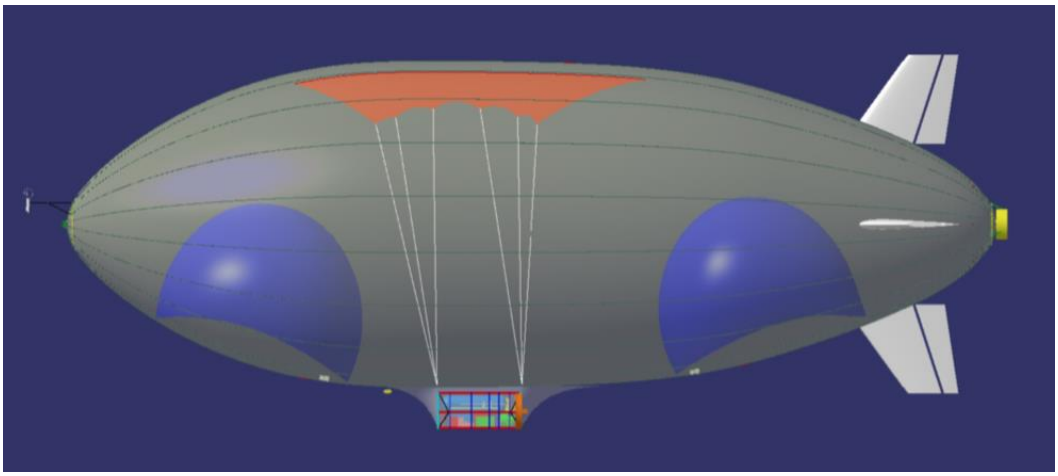
1. Introduction

Between 2007 and 2013, Shanghai Jiao Tong University's (SJTU) Chongqing Nearspace Innovations R&D Center developed and flew two small, unmanned, low-altitude, non-rigid airships that were used to develop flight controls and test designs for a future stratospheric airship. These airships, the Zhiyuan-1 (ZY-1) and Tianzhou-1, are described in this article.

2. Zhiyuan-1 (ZY-1) airship (2007 – 2009)

The Zhiyuan-1 (ZY-1) is an unmanned conventional blimp that appears to have been built by Suzhou Ark Aviation Technology Co. Ltd. (SAS) and was equipped and flown at low altitude by SJTU from 2007 to 2009 as a flight control system technology demonstrator for a future stratospheric airship. This 25 m (82 ft) blimp had two ballonets, an external gondola suspended via internal catenaries, three propellers (two on the gondola, one at the tail) and cruciform tail fins with aerodynamic control surfaces.



Zhiyuan-1 airship general arrangement, showing two ballonets (blue), catenary curtain (ochre) supporting the gondola, and the tail-mounted propeller (yellow). Source: X. Ning, et al. (2021)

The all-electric power system is comprised of a hydrogen fuel cell and batteries for propulsion and a lower voltage battery for flight control and payload systems. A three propellers layout was adopted, with two thrust vectoring shrouded propellers cantilevered from the sides of the gondola, and one fixed shrouded propeller mounted at aft end of the envelope.

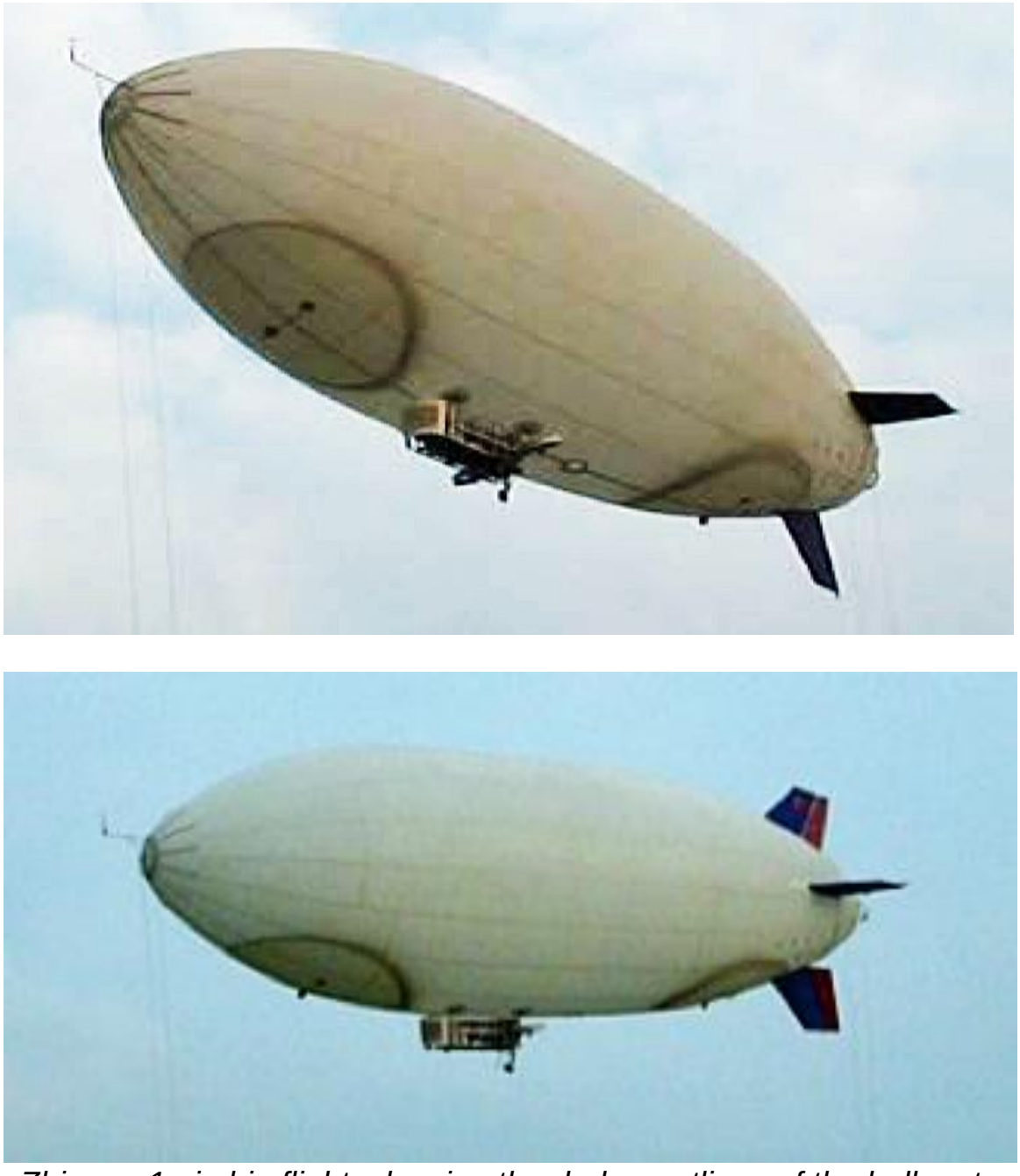
Flight control during cruise is provided by conventional rudder and elevator control surfaces on the cruciform tail fins. At low speed, when the aerodynamic control surfaces are ineffective, the thrust vectoring propellers provide control for maneuvering.

General characteristics of the Zhiyuan-1 airship

Parameter	**Zhiyuan-1 (ZY-1)**
Length	25 m (82 ft)
Diameter, max	7.5 m (24.6 ft)
Fineness ratio	3.3
Envelope volume	750 m^3 (26,486 ft^3)
Power system	Hybrid hydrogen fuel cell / battery system provides 300V for propulsion power: • 10 kW fuel cell with 140 L / 20 Mpa (40 gallon / 2,900 psi) gaseous hydrogen tank • 6.0 kW Li-ion battery 1.2 kW Li-ion battery provides 28V for flight control system and payload
Propulsion system	• 2 x thrust vectoring, 300V electric motor-driven shrouded propellers cantilevered from the gondola • 1 x fixed, 300V electric motor-driven shrouded propeller mounted at the aft end of the envelope • Total propulsion power: 8 kW (10.7 hp), split 1.0 : 1.1 between the gondola motors and the tail motor
Station keeping	± 100 m (328 ft) in autonomous flight control mode
Wind speed, max	8 m/s (29 kph / 18 mph) design, 10 m/s (36 kph / 22.4 mph) demonstrated
Altitude max	800 m (2,625 ft)
Endurance, max	4 hours (design), 80 minutes demonstrated

Flight control system included a manual remote controller and an autonomous control system, which could be engaged and disengaged in flight. An operator in a mobile ground station installed in a minibus could exercise full remote control or, during autonomous

flight, update course and waypoints. The ZY-1 flew a total of 12 test flights between September and December 2009. On these flights, manual control was used for takeoff and landing. Autonomous controls were demonstrated in flights lasting up to 80 minutes.



Zhiyuan-1 airship flight, showing the darker outlines of the ballonets inside the envelope. Note that the shrouded propellers on the gondola are vectored horizontally to provide lift.
Source: X. Ning, et al. (2021)

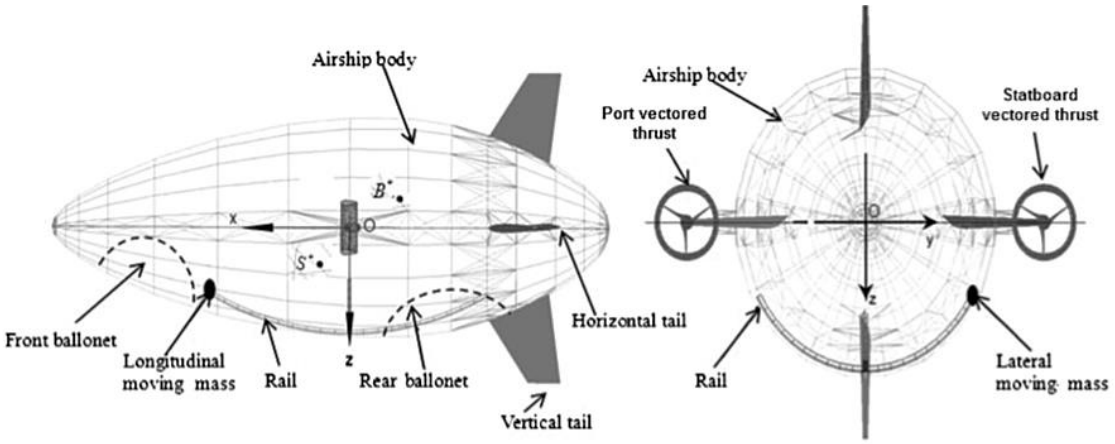
Zhiyuan-1 airship moored. Source: X.L. Wang, et al. (2010)

Zhiyuan-1 in flight.
Source: Suzhou Ark Aviation Technology Co. Ltd.

3. Stratospheric airship design concept (2012)

In 2012, SJTU reported on a stratospheric airship design concept with a composite control system that combined conventional aerodynamic control surfaces, dynamic vectored thrust, and air ballonets with an unconventional moving-mass control system.

The latter was introduced to provide better flight control at low airspeeds and in the low atmospheric density of the stratosphere. Longitudinal and lateral rails are installed along the bottom of the hull and are part of the airship. Two moving masses are installed, one in each rail (m_{lon} & m_{lat}), and their locations along the rails are precisely controlled.



Stratospheric airship with longitudinal and lateral moving masses for pitch and roll control. Source: L. Chen, et al. (2012)

The authors of the 2012 SJTU study concluded:

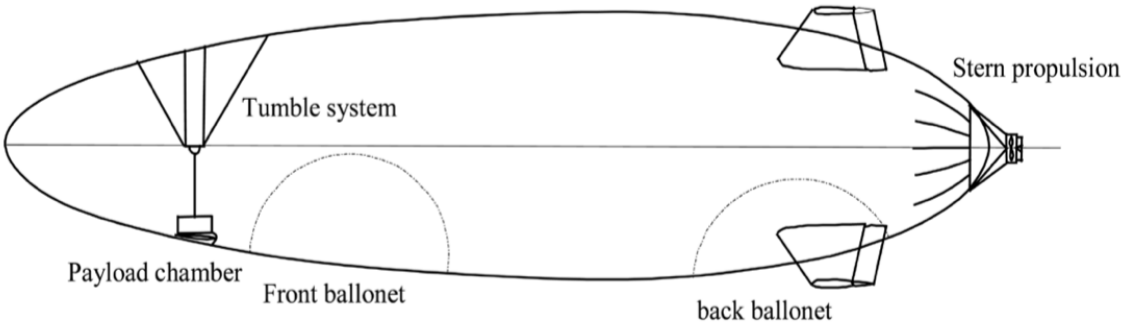
- The moving-masses change the center-of-gravity of the airship.
- The moving-mass ratios (Total mass vs. m_{lon} & m_{lat}) and the displacements of the moving masses are the primary factors affecting moving-mass attitude control capability.
- Moving-mass control is independent of velocity.
- At very low airspeed (including hovering), moving-mass control is more effective than aerodynamic control.
- Gliding flight can be achieved with precise buoyancy & pitch control.
- Moving-mass control is easy to implement.

This SJTU composite control system was not flight tested.

In principle, this moving-mass control system is very similar to the moving-mass control system (Mass Transfer Unit, MTU) designed in the mid-1970s by Michael Walden for toroidal airships and later patented and tested at full-scale by LTAS.

4. Tianzhou-1 airship (2013)

Tianzhou-1 is a very streamlined airship with an X-tail, a single thrust-vectoring propulsor mounted at the aft end of the envelope, and an internal equipment bay supported by catenary cables from the upper surface of the envelope.



Tianzhou-1 airship general arrangement.
Source: X. Ning, et al. (2021)

Tianzhou-1 airship. Source: X. Ning, et al. (2021)

This general arrangement is reminiscent of the StratSat stratospheric communications airship that was being developed between 2001 – 2006 by the British firm ATG.

Like the ZY-1, the flight control system included a manual remote controller and an autonomous control system, which could be engaged and disengaged in flight.

Flight tests of the Tianzhou-1 airship were conducted from January to December 2013. The main goals of these tests were to verify flight performance and stability of an airship with a single thrust-vectoring propeller at the stern. During these tests, the airship typically flew at altitudes between 300 to 500 m (984 to 1,640 ft).

General characteristics of the Tianzhou-1 airship

Parameter	**Tianzhou-1**
Length	20 m (65.6 ft)
Diameter, max	5.3 m (17.5 ft)
Fineness ratio	3.75
Envelope volume	300 m^3 (10,594 ft^3)
Power system	Li-ion battery delivering 3.3 kW/300V to the propulsion system and 435 W/28V power to flight control and payload systems
Propulsion system	1 x DC motor (3.3 kW/300V) (4 hp) driving a single, tail-mounted, ducted propeller with 4 x flow deflectors in the slipstream to provide thrust vectoring
Station keeping	±100 m (328 ft) in autonomous flight control mode
Wind speed, max	10 m/s (36 kph / 22.4 mph, design)
Altitude max	500 m (1,640 ft)
Endurance, max.	1 hour (design)

5. For more information

- X.L. Wang, G. Fu, D.P. Duan and X.X. Shan, “Experimental Investigations on Aerodynamic Characteristics of the ZHIYUAN-1 Airship,” Journal of Aircraft, Vol 47. No. 4, July – August 2010: https://arc.aiaa.org/doi/abs/10.2514/1.C000243
- L. Chen, et. al, “Composite Control Strategy of Stratospheric Airships with Moving Masses,” Journal of Aircraft, Vol. 49, No. 3, pp. 794 – 801, May – June 2012: https://rcns.sjtu.edu.cn/wp-content/uploads/2017/06/Composite-Control-Strategy-of-Stratospheric-Airship-with-Moving-Masses.pdf
- L. Ping, G. Fu, L. Zhu & X.L. Wang, “Aerodynamic characteristics of airship Zhiyuan-1,” Journal of Shanghai Jiaotong University (Science), Vol. 18(6), pp. 679-687, December 2013: https://www.researchgate.net/publication/271742334_Aerodynamic_characteristics_of_airship_Zhiyuan-1

- X. Ning, P. Liu & Z. Pan, “The Mechanical Characteristics and Experimental Study of the Stratospheric Airship,” Journal of Applied Mathematics and Physics, Vol. 9, pp. 183-196, 2021: https://www.scirp.org/pdf/jamp_2021012814484899.pdf

Other *Modern Airships* articles

- *Modern Airships - Part 1*: https://lynceans.org/all-posts/modern-airships-part-1/
  - *ATG – StratSat*
  - Lockheed Martin / DARPA – HALE-D
  - StratoComm Corp – STS
  - Walden LTAS_Lenticular toroidal DCB airships
- *Modern Airships - Part 2*: https://lynceans.org/all-posts/modern-airships-part-2/
  - *Sceye Inc. – Stratospheric airship*
  - ESA / Lindstrand – HALE aerostatic craft
- *Modern Airships - Part 3*: https://lynceans.org/all-posts/modern-airships-part-3/