1 Introduction

Gabriel Alexander Khoury

This book is intended as a technical guide to those interested in studying, designing, building, flying, and operating the airship of today. Although the book aims towards the future, mention is made – where appropriate – of the experiences of earlier years when these point out relevant information.

This edition has four themes. The first theme is the *basic scientific/engineering principles* of airships, which was the main theme of the first edition. To this first theme I have now added chapters on meteorology and ground handling. The second theme of this new edition is the *type of airships*, as these are varied: conventional ellipsoidal airships (e.g., Zeppelin New Technology), hybrid tri-lobed lifting body airships (e.g., hybrid air vehicles), unmanned airships, hot-air airships, and human powered airships. The third theme is *applications*, such as geological surveys, communications, passenger services, media, surveillance, and advertising. Examples of this theme are chapters on heavy lift and disaster and humanitarian relief. The final theme is *economic considerations*. The future of airships rests, to a large extent, on their economic viability, which is closely related to their unique characteristics, the specific roles that airships are able to fulfil, and their market potential.

Modern airships employ advanced technologies such as composite materials, computerised numerical finite element structural analysis, computer-aided design, modern electronic systems, fly-by-light controls, and the latest theories in aerodynamics, as well as stability and control. Some aspects of modern design are borrowed from other disciplines, whereas in certain areas, such as envelope fabrics and automatic docking systems, the technology is developed specifically for the airship. Mainstream aeronautical data are available in numerous publications and are not duplicated herein. This book is, therefore, devoted to the aspects of design and operation that are particular to airships.

A distinguishing feature of airships is their reliance on a light gas for lift. It is necessary, therefore, that all those involved with airships have a good understanding of the basic principles of aerostatics. A brief outline of the subject is given in Chapter 2 on basic principles, and a more detailed treatment is given in Chapter 8 on aerostatics.

The bare hull of the conventional airship is of the classic streamline form. The conventional airship is, however, essentially a low-speed vehicle, with the power requirement being approximately proportional to the cube of the airspeed. Higher speeds require a rapid escalation of weight and fuel consumption, whereas structure weight increases to meet the higher aerodynamic loading. Despite elegant streamlining, the aerodynamic drag of an airship is high. For a typical airship in steady axial flight, part of the total aerodynamic drag owes its origin to the bare hull; the remainder is generated by fins, engines, and the control car. The latter appendages produce drag not only because of their own resistance, but also through their interference with the flow over the main hull. The 'bare hull' drag could account for about 60 percent to 70 percent of the total, the proportion increasing with airship size as the appendages become smaller in relation to the hull. The aerodynamics of airships is briefly discussed in Chapter 2 (basic principles) and in more detail in Chapter 3 (aerodynamics). Boundary layer control is also discussed in Chapter 16 on improvements.

The most significant contribution to the development of the stability and control of the modern airship (Chapter 4) stems from advancements in computer technology. It is now feasible to undertake hitherto difficult, if not impossible, analysis and simulation, which has enabled the attainment of new levels of insight and understanding. This, in turn, has encouraged the development of more detailed and more accurate aerodynamic and dynamic models of the airship, culminating in extremely comprehensive nonlinear simulation models. The digital computer is now also firmly established for the control of air vehicles and is the nucleus of the electronic flight control systems (EFCSs), which can be used to very good effect in the airship. The euphoria, however, is tempered when it is realised that the performance of the EFCS is limited by the effectiveness of the aerodynamic control surfaces it drives. New developments may overcome this limitation to a certain extent by integrating control of the propulsion unit thrust vectoring into the overall control strategy.

The importance of good weight estimates and control (Chapter 9) during all phases of the design of an airship, especially in the early stages, cannot be over emphasised. The amount by which the airship is 'overweight' has a more direct effect on the performance than it would on a conventional fixed- or rotary-winged vehicle. Every additional kilogram of weight is one kilogram lost in available payload. Also, because an airship is very fuel efficient, any lost fuel capacity through this increased weight has an effect on endurance, which can be several orders of magnitude greater than for a heavier-than-air aircraft. Because endurance is one of the primary benefits of an airship – and in many cases its sole *raison d'être* – accurate preliminary weight estimation, and strict weight control, are vital.

Many of the major developments in materials of this century, particularly in the areas of specific strength, have been instigated by the aerospace industries. These developments and advances have fundamentally changed the design of aircraft. The introduction of such materials as lightweight strong alloys, fibre-reinforced composites, or honeycomb materials has had a major impact on the design of aircraft structures, whereas improvements in high-temperature properties through alloy development and manufacturing methods (e.g., directionally cast, single crystal, or metal matrix composite turbine blades) have transformed engine technology. Most of these developments, especially the introduction of stronger lighter materials (e.g., Kevlar), have helped airship design through lighter gondolas, nose cones, battens, and tail fins. These consequences are a spinoff from material developments aimed at conventional airframe, rather than as airship-specific, developments. However, major developments in textile engineering have been uniquely responsible for advances in airship design; for this reason, Chapter 6 on materials considers those developments only. The advances in other structural materials have been covered adequately in other publications.

Airship structures are described in Chapter 7. In earlier airships, stress analysis was conducted laboriously and manually with the risk of errors in the calculations always being present. Structural analysis has since benefitted considerably from the introduction of computerised finite element stress analysis methods. This, added to the advances in material sciences, joining techniques, design aids, atmospheric awareness, and aeronautics, allows the opportunity for efficient modern airships to be introduced at competitive prices.

Systems are the physical means of achieving a designed function. They consist of components, control mechanisms, and sensors. Some systems are essential to the operation of others, such as those that are power sources; examples are electrical, hydraulic, and pneumatic systems. Airship systems include most of the major and minor groups found on all aircraft and a few that are peculiar to lighter-than-air aircraft. The items described in Chapter 10 on systems can be found on most airships, but the design, complexity, and location may differ considerably from type to type. Some systems may be peculiar to airships designed for particular missions, such as an inflight replenishing in military applications. The major systems not covered in Chapter 10, such as stability and control and propulsion, are instead described in Chapters 4 and 5, respectively.

The issue of mooring and ground handling (Chapters 11 and 12) is still seen as one of the most problematic areas of airship operation. Significant improvements are taking place in this area, however, with the development of thrusters and automatic docking systems. The future solution of ground handling and mooring requirements is very closely associated with the provision of adequate control to enable precise low-speed flight to be undertaken reliably and safely. Given this, the remaining issues are concerned with ensuring that the structure of the airship is of adequate strength to resist the loading anticipated whilst the craft is moored. Ground handling (GH) of 'conventional' airships has always been the poor cousin of airship operations. Chapter 12 attempts to change this view and re-establish GH in its central role as the vital foundation on which all airship operations must invariably stand. The future success of all new or next-generation conventional airship development projects depends on the recognition of its true nature from the very outset and the full integration of GH into the design process, with the allocation of proper resources and adequate funding.

The tasks of the pilot described in detail in Chapter 14 on piloting are valid for small and medium-sized nonrigid airships up to about 20,000 m^3 volume. Nonrigid airships larger than this are likely to require amended techniques, as they would exhibit different characteristics owing to their size, mass, and inertia. Rigid airships will require different techniques, owing to their greater options on ballast, mass, power plant, and gondola (or car) locations, as did the great rigids of the past. The differences in piloting an airship from that of fixed- or rotary-wing flight includes lower speeds and slower responses, dependence on the availability of a GH party, and the possibly greater impact of certain meteorological conditions. Every landing is different, owing to a combination of meteorological, locational, and on-board factors. The airship pilot must, therefore, become almost a part-time meteorologist. It appears that pilots of rotary-wing and fixed-wing aircraft can make equally good airship pilots. However, some pilots who have spent 20 years or more flying at 400 knots may experience more than a little difficulty in adjusting to the low-speed environment and, indeed, may never quite master airship flying. Airship pilots would, however, benefit from at least some basic flying training in heavier-than-air craft, alongside which they will eventually have to operate.

Because the airship pilot almost needs to become a part-time meteorologist, particularly with global climate changes, it was necessary to introduce, in this second edition of the book, a new chapter dedicated to meteorology (Chapter 13). Atmospheric science developed steadily throughout the last century of airship development, and in the twenty-first century, the relatively limited number of operational piloted airships is serviced in many countries by greatly improved national aviation weather forecasting services. However, airships remain very weather-sensitive in most phases of flight, and not every country can provide an aviation weather forecast which contains all the vital information appropriate to the special operational needs of an airship pilot or airship operator. Furthermore, the acceleration of global atmospheric warming is already producing new patterns of weather and climate in some regions of the world, for which reliable weather forecasting models have so far not been developed; this places much more of the responsibility for flight safety on the ability of the airship pilot and the flight operations planner to adapt airship operations to the prevailing conditions, almost irrespective of the availability of a specialised professional weather forecast. Chapter 13 illustrates the extreme weather-sensitivity of piloted airship operations to a wide range of different weather processes, and indicates some important effects which different weather hazards may have on different phases of airship flight operations at different geographical scales. The focus of this chapter is therefore on the very practical needs of airship pilots and airship operations managers to acquire a basic understanding of the nature of the relevant weather processes, and to make use of the relevant diagnostic meteorological information to enhance the safety and efficiency of airship operations.

The payload limitations of heavier-than-air aircraft are, in most cases, imposed by airfield performance and weight, altitude, and temperature-limited climb considerations. In contrast, the payload of airships is generally limited by the gas lift available in the climatic conditions prevailing at the cruise flight altitude. This means that the key cruise altitude, temperature conditions, payload, and mission profile must be established very early in the design process, as alterations to these can cause big changes to volume. Only at extremely short airfields does take-off performance become a limitation. This and other comparisons with heavier-than-air aircraft are explained in Chapter 15 on performance. Points of difference that are known to have caused misunderstandings are dealt with first.

Many of the airship's principal operational problems are associated with the functions of buoyancy control, of fuel consumption and of interface movements – that is, landing, mooring, load exchange, and take-off. Certain modifications to the basic airship concept have been introduced in recent years which help to some extent in these areas. An obvious example is vectored thrust – originally used on a number of early airships before World War II and then reintroduced for the Airship Industries Skyship series in the 1980s and later with the Zeppelin NT series. Control effectiveness has also been improved, with reduced pilot effort, in experimental ships using fly-by-wire or fly-by-light transmissions in place of direct tension cables. The U.S. Navy's rigid airships of the 1930s also used exhaust water recovery, with some success, to reduce in-flight weight loss owing to fuel consumption; this technique has also been proposed for modern diesel-powered projects, although such an installation does not yet appear to have flown. In addition to these proven expedients, many other theoretical approaches to buoyancy, fuel consumption, and interface problems are constantly being proposed. Many of these are impractical, usually because of the weight penalty involved. Other ideas may have a marginal applicability in particular cases. Such proposals are made repeatedly by different agencies. Chapter 16 on improvements, therefore, sets out to survey briefly, and to evaluate critically, some of the more common of these concepts.

Unconventionality may be attributed to an airship if a major feature of the design is significantly altered from the 'conventional', such as the overall shape, method of lift, source of power, structural configuration, type of lifting gas, or mode of control. These are described in Chapter 19 on unconventional designs, which looks at hybrid (dynastats, rotastats, and rotating-hull airships), unmanned, metal-clad, hot-air, solar, and human-powered airships, and even a design that incorporates hydrogen as part of a multi-chamber, multi-gas configuration. Coverage is given to the tri-lobe lifting body hull hybrid airship, which has gained much interest and attention in recent years. An example is the Hybrid Air Vehicles airship, in which conventional buoyant lift provides some 60 percent of total lift, vectored thrust provides typically ± 25 percent, and aerodynamic lift provides an increased lift of about 40 percent. Such vehicles are expected to play various roles, from operations in remote areas (e.g., Canada and Russia), survelliance, to disaster relief and civil engineering lifting roles. Chapter 26 is dedicated to some aspects of the aerodynamics of this hybrid airship. Chapter 19 also describes some of the current solar-powered airship projects, whether low altitude or high altitude, and whether manned or unmanned. It also looks at heavy lift and different structural configurations.

A more detailed mathematical description is given, however, for the cases of the lenticular and solar-powered airships in Chapters 14 on improvements and 16 on solar power, respectively.

Chapter 17 is devoted to design synthesis of the complete airship, which integrates many of the disciplines discussed in earlier chapters on the first theme of the book – a necessary process for achieving satisfactory design.

The design of 'conventional' airships has reached new technical and operational advancement with the Zeppelin New Technology (NT) series (Chapter 21). The Zeppelin NT combines the design principles of a blimp and a rigid airship. A new concept of the semirigid airship has been redefined. Computer-aided design (CAD) tools, new materials, and new system layouts were design elements for creating the most conventional modern airship in the world. This type of airship overcomes some of the typical disadvantages of airships. A higher degree of safety in all operational phases, an extreme high manoeuvrability, and the design for multipurpose missions guarantee a much better economical operation in comparison with other ancient and existing airships. The propulsion system, together with the internal rigid structure, offers significantly enhanced safety. Even a collapse of the envelope as a result of pressure loss – a problem with blimp-type airships – does not render the Zeppelin control-less. In addition, a safe landing in a two-engine-out (out of three) situation was proven during the certification period. Four Zeppelin NTs were produced between 1997 and 2007. Three are flying successfully in Europe, Japan, and the United States. Nearly 100,000 passengers have experienced the wonderful flight atmosphere so far. This comprehensive chapter provides a general description of the Zeppelin NT and then delves in detail into the flight performance data, the structure, cockpit, gondola, cabin, landing gear, propulsion system, engines, fuel system, flight control, electronic flight instrument system, hydraulic system, electrical systems, and ground operations.

There has also been increased interest and activity in relatively low-cost unmanned airships for low-altitude (and high-altitude) applications (Chapters 19 and 22), in which the human element is taken out of the direct loop. The comprehensive Chapter 22 is dedicated to unmanned airships variously described as unmanned aerial vehicle (UAV), remotely piloted vehicle (RPV), and unmanned aircraft system (UAS). These airships encompass all classes of powered LTA vehicles: They can be rigid, semirigid, or nonrigid; they can be ellipsoidal, spherical, lenticular, or hybrid; and they can be from a few cubic metres to several hundreds of thousands of cubic metres in volume. Their role will shape the key design drivers. In fact, design drivers for unmanned airships are essentially no different from those for manned airships. Design drivers include weight, altitude, speed, endurance, certification, aerostatics, aerodynamics, materials, structures, power plant, performance, and flight control and communications. Potential roles of unmanned airships are varied and can include advertising and media, surveillance, communications, and even passengers and heavy lift applications, as described in this chapter. Examples of unmanned airships given include the Lindstrand GA22Mk2 and the SAIC Skybus30K.

Hot air airships are popular for sport (as well as for aerial advertising and environmental research); this subject is covered in this edition by a leading expert (Chapter 23). Examples include airships by Cameron Balloons, Thunder & Colt Balloons, and GEFA-FLUG Ltd. The chapter provides the general characteristics of hot air airships and compares hot air airships with helium airships. Applications first started with aerial advertising but then developed into environmental monitoring and geophysical surveys. The operational experiences are described, as well as the technical development and achievements of the GEFA-FLUGAS 105. The chapter looks into the future of hot air airships in terms of possibilities and limitations. It describes pilot licenses and crew training and ends with mention of the European Airship Alliance between GEFA-FLUG Germany and Cameron Balloons UK.

Chapter 24 is devoted to the subject of human power for airships. It starts with the survey of recent human-powered dirigibles and compares them in terms of dimensions, volume, and airspeed. Clearly, human factors are critical to this design. The author delves into human factor engineering, in which the major human factor issues are anthropometrics and biomechanics. Typical areas include fit analysis, visibility analysis, reach analysis, and strengths for operating controls with arms and legs. Software programs offer various human figure models with associated analysis. The chapter then presents a comprehensive list of design issues, as well as a simplified systems engineering process and functional analysis. A design brief is presented, along with two alternative fanwing ideas for human-powered dirigibles. The chapter progresses with a description of the dirigible envelope and dirigible forces such as buoyancy lift, aerodynamic lift, and dirigible resistance. A mathematical description is then given for propelling power, followed by the description of the envelope material and envelope design. In designing a human-powered dirigible, two very important design criteria in envelope design involve minimising envelope weight and propulsion power. Both factors depend on the size and shape of the envelope. The envelope shape and size affect aerodynamic forces. Optimisation of shape demands testing. One testing method is to use a wind tunnel. It is in the interest of a designer to explore the aerodynamic properties of a design with the aim of reducing air drag arising from the design of the dirigible and the position of the pilot and the aerodynamic fairing provided. Conputational fluid dynamics (CFD) analysis offers an ideal tool for this work. Design activities must also focus on the propulsion system and propeller design. Analysing how a propeller generates thrust is very complex. However, using simplified momentum theory the fundamentals can be presented mathematically (see the end of the chapter).

On the third theme of this book (applications) are added two chapters on heavy lift and disaster and humanitarian relief.

The future of airships rests, to a large extent, on their economic viability, which is closely related to their unique characteristics, the specific roles that airships are able to fulfil, and their market potential. These are the considerations examined in Chapter 18 on roles and economic considerations.

Given the inherent lifting capacity of airships, there has been, for nearly half a century, an interest in their use for heavy lift applications such as logging and civil engineering. The chapter dedicated to *Heavy Lift* brings together some of the designs, whether by means of the aerostat (e.g. SkyLifter and CargoLifter), dynastat (e.g., tri-lobed HAV) or rotastat (e.g., Skyhook JHL-40) airship options (Chapter 25). The aerostatic Varialift project is discussed in Chapter 19.

The airship, of all vehicles, may be particularly suited for disaster and humanitarian relief (Chapter 27). Views exist that if cargo airships had been available for humanitarian relief operations when the Haiti earthquake occurred, literally thousands of lives could have been saved. Natural disasters need large quantities of goods transported into unprepared sites at very short notice. Current airlift capabilities are far less than those available for a heavy-lift airship. Its ability to take off and land vertically also allows the airship to reach remote areas not accessible by fixed-wing aircraft. The airship would satisfy many specific humanitarian logistics needs which cannot be met by current modes of transport. It can deliver fresh water, food, and medicines, as well as engineering machinery and large-scale disaster relief equipment. The airship can stay in an area for long periods of time, facilitating 24-hour-long searches and deliveries to disaster-stricken people (something helicopters are not able to achieve). Airships could also provide remote sensing and communication functions for earthquake relief work. In cloudy weather, airplanes and satellites cannot promptly obtain clear remote sensing images, but an airship can cruise for long periods of time under cloud layers.

Cambridge University Press
978-1-107-01970-6 - Airship Technology: Second Edition
Gabriel Alexander Khoury
Excerpt
More information

2 Basic Principles

Edwin Mowforth

Introduction

This chapter deals with some of the basic parameters of airship design and operation under the headings:

- Principles of Aerostatics
- The Aerostatics of the Airship (see also Chapter 8)
- The Aerodynamics of the Airship (see also Chapters 3 and 26)
- Unconventional Designs (see also Chapter 19)

Most of these topics will be developed further in later chapters; the objective here is to offer an overview that will help tie the more detailed treatments together.

Principles of Aerostatics

The term ‘aerostatics’ refers to the static buoyancy of any kind of body immersed in the atmosphere, just as ‘hydrostatics’ describes the same effect in water. In both cases the upward buoyancy force is equal to the weight of fluid displaced, which in air may be taken as:

$$B = V \cdot \rho_a \tag{2.1}$$

where

B is the upward buoyancy force acting on the body
V is the volume of the body
ρ_a is the mean density of the local atmosphere surrounding the body

(ρ_a will have a slightly nonlinear variation over the height of the body arising from the curvature of the natural atmospheric pressure gradient, but a mean value in Equation 2.1 will be accurate enough for all practical purposes).

This buoyancy force acts on all bodies within the atmosphere but is usually negligible compared with the weight of the body itself; the buoyancy of a human being at sea level, for example, is only about 0.12 percent of body weight. If, however, the weight W of the body can be made less than that of the displaced air, then there will be a net upward lift L given by:

$$L = B - W \tag{2.2}$$

The obvious case to be considered is that of a balloon incorporating a closed flexible envelope of volume V filled with a gas of density ρ_g, which is less than ρ_a – for example, hydrogen or helium. The total weight of the system will then be:

$$W = V \cdot \rho_g + W_o \tag{2.3}$$

where W_o is the weight of the envelope and all its attachments. In any real case, the volume of the structure represented by W_o will be so small compared with V that its buoyancy will be negligible, and Equations 2.1, 2.2, and 2.3 may then be combined to give:

$$L_d = V(\rho_a - \rho_g) - W_o = L_g - W_o \tag{2.4}$$

In Equation 2.4, L_d is the 'disposable lift' of the gasbag; this is the lift available for crew, fuel, payload, ballast, and supplies when the fixed 'empty' weight W_o has been subtracted from L_g, the 'gross lift' of the gasbag.

The term $(\rho_a - \rho_g)$ represents the gross lift per unit volume, or 'unit lift', of the combination of gas in the envelope and air outside it. At sea level in the International Standard Atmosphere, if the lifting gas is at the same temperature as that of the ambient atmosphere, pure hydrogen, for example, offers a unit lift of 11.183 N/m^3 (0.0711 lb/ft^3), whereas pure helium, being twice as dense as hydrogen, generates the slightly lower unit lift of 10.359 N/m^3 (0.0659 lb/ft^3).

The actual mechanism of aerostatic lift is explained in Figure 2.1, which shows a sealed flexible envelope, assumed weightless, containing gas of density ρ_g, at rest in an atmosphere of local mean density ρ_a. The envelope is partially collapsed, its lower surface thus being drawn up into a flat plane on which the inner and outer pressures are equal. (This 'flat' appears at the bottom because the lifting gas is less dense than air; if it were more dense, the flat would be at the top).

Starting from this level and working upwards, the internal and external pressures will both fall off with height and rates proportional to the respective densities, so that at a height 'h' above the base the internal pressure will have fallen by $\rho_g \cdot h$ and the external pressure by $\rho_a \cdot h$. The latter deficit will be greater, so that a differential pressure of $(\rho_a - \rho_g)h$ will act outwards across the envelope skin; this wedge-shaped pressure distribution, spread over the internal surface of the envelope, will both prevent its collapse and furnish the resultant upwards force represented by the 'gross lift' term $V(\rho_a - \rho_g)$ in Equation 2.4. The pressure difference itself is small; at the top of a hydrogen gasbag 30 m (98 ft) high at sea level, for example, it will reach only 335 N/m^2 (7 lb/ft^2), or about 1/300 of atmospheric pressure. With helium, the pressure difference would be about 7 percent smaller.

The gross lift of a gasbag is determined by its volume V and is totally independent of its shape. Free balloons, however, tend to favour a form approaching the spherical, because this offers both the smallest surface area to contain a given volume and the

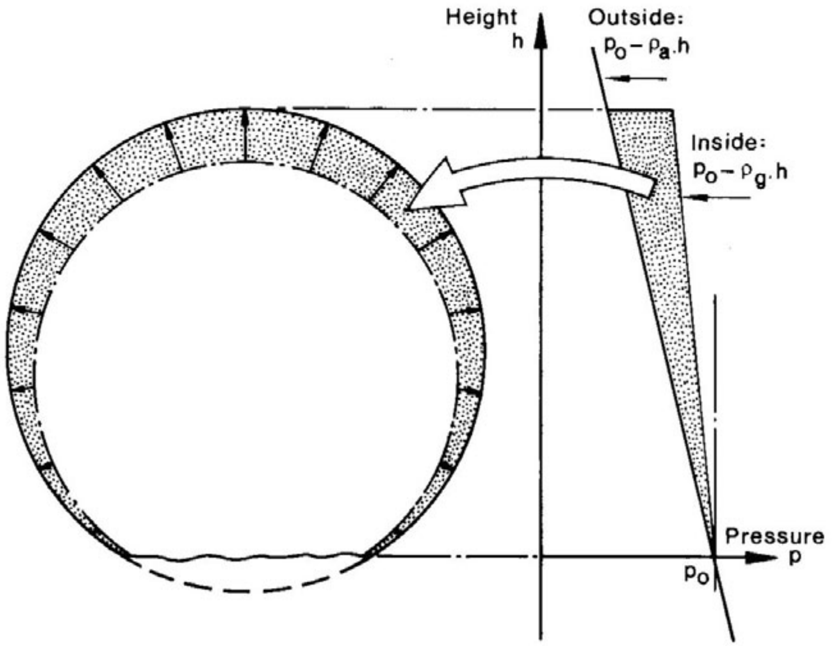

Figure 2.1. The mechanism of aerostatic lift.

lowest skin tension for a given pressure difference across the skin; both factors facilitate a minimum-weight design.

As long as the gas in the envelope is free to expand – that is, the envelope is only partially filled – and the gas and air temperatures remain equal, the disposable lift L_d given by Equation 2.4 does not change with altitude. As the gasbag ascends, the gas and air densities fall with decreasing pressure but the gas volume V increases in the same ratio. Conversely, falling temperature tends to increase the densities but reduces the volume, so the two effects again cancel out.

In any 'real' atmosphere, the fall in pressure with altitude has a more pronounced effect than the corresponding fall in temperature, so during ascent the gas will continue to expand until the gasbag is completely filled and no further expansion is possible. The altitude at which this occurs is termed the *pressure height*, because further ascent will cause the differential pressure across the skin of the gasbag to increase; the lift, however, will decrease.

In conventional airships and balloons the gasbag skin, for minimum weight, is not designed to carry stresses far in excess of those encountered below the pressure height, which is therefore regarded as an operational ceiling. If this height is exceeded in an emergency, safety valves release gas to protect the envelope against pressure rupture. In recent years, however, high-altitude research has increasingly involved the use of unmanned 'pressure balloons' using envelopes that are strong enough to exceed the pressure height by a significant margin without rupture or gas release. These balloons are so designed that the net lift is positive, causing continuing ascent, above the pressure height; in rising further, however, the net lift falls to become