METALCLAD AIRSHIPS

By Vladimir H. Pavlecka and John W. Roda

History

At this time of transition into the third century of our independence, it is appropriate to bring out a singular achievement of our technological history of half a century ago; to assess its merits in the now vastly different world, strong in sophisticated technical competence and also, to project its promise into the immediate and continuing future of the next century.

Over fifty years ago, two talented, dissimilar but highly complementary men of our Midwest, independently originated the concept of all-metal airships; Carl B. Fritsche and Ralph H. Upson. Their dream was the design and construction of what they called Metalclad airships. They found each other and joined their efforts in one of the most brilliant achievements of our national genius. Upson generated the intellectual, creative design power and Fritsche the motive, political and financial power, the directing purpose of the Metalclad airship program. It was a unique privilege, a sense of "being chosen", for all of us younger ones, to work under the guidance of these two extraordinary men.

Their most difficult and arduous efforts of several years finally resulted in a Federal contract for the prototype Metalclad airship, the ZMC-2, to be constructed for the U. S. Navy by Aircraft Development Corp. which Fritsche and Upson organized for this purpose. ZMC-2 was completed in August 1929, exceeding all design expectations, flown with success and delivered in a cross-country flight from Gross Ile near Detroit, to Lakehurst, N. J., by the completely dedicated Metalclad airship pilot, Maj. Gen. Ret. (then Captain) W. E. Kepner. It was in service over 12 years until dismantled, it was said, for lack of hangar space. Its performance as well as nondemanding durability was excellent. It was the harbinger of a new, rational direction of future airship construction during the decade of four catastrophical disasters of Zeppelin-type airships which terminated further development not only of fabric-covered skeletal airships, but of all rigid airships, including the Metalclad types.

After WWI, Upson had the imagination and courage to realize that fabric-covered skeletal hulls of Zeppelin airships suffered from insurmountable inadequacies, in fact shortcomings, which grew out of proportion with increasing size of the hulls, and that new and appropriate principles of design and construction would have to be found and relied upon for future dependable and useful buoyant airships; that these airships would have to fly at much higher speeds, require smaller crews and minimal maintenance and finally, that airships would have to be taken out of the grip of weather and become independent of it. He developed the principle of rigid hull airships as fire-resistant shells, fabricated completely of light metal, pressurized by controllable means for increased strength and rigidity. A Metalclad airship was to be an inherently rigid structure, even without lifting gas with its helpful pressure; structurally, it was to be more than equivalent in this state to the skeletal structure of Zeppelin hulls. Lifting gas in any airship creates pressure inside the hull, increasing from zero gage value at the lowest part to a maximum gage pressure at the top of the hull. In Zeppelin hulls, this unavoidable pressure difference, which in turn lifts the airship, is a problem and a nuisance. It requires tens of thousands of diagonal steel wires between longitudinal girders or longerons and transverse frames as a network for the cell fabric to lay on under internal lifting gas pressure. These wires then load the girders in compression and the cell pressure additionally loads all girders in bending.

In Upson's Metalclad hull, the gas pressure loads the metal skin of the hull shell in tension, longitudinally as well as transversely. The longerons also are loaded in tension, as are the transverse frames, while locally, due to imposed weight loads, the latter will be in compression, stabilized by taut hull plating. From the frames, loads are distributed into the shell by shear in the hull metal skin. Due to gas pressure alone, this state of loading is increasingly useful to the shell structure toward the upper half of the hull; the lower part of the hull benefits from it only little, if at all. Therefore, Upson pressurized the whole metal hull by superimposed pressure over and above the gas pressure and made the entire hull shell work in tension and shear, thus creating a simple metal structure of great strength and rigidity, highly redundant in support of loads and to local damage, without complexity. Any structure designed for supporting imposed loads in tension and shear is always the strongest and the lightest. In contrast, any structure supporting imposed loads in compression and bending, will always be heavy and less reliable.

Upson recognized the fundamental value of using pressure in rigid airships and made use of it without jeopardizing their structural integrity in case of irreparable loss of both, the gas as well as the superimposed pressure. In the latter case, all projected designs of Metalclad airships would have been capable of flying at reduced speed, as much as one half of their maximum speed, and reach home. Upson's solution of using internal pressure for strength and rigidity, was intended for containing the lifting gas securely in a light-weight metal hull structure capable of flying safely in rough weather; it had also the purpose of reaching as well as maintaining high flight speeds. Upson was mercilessly criticized through the third decade of this century by almost all who uncritically accepted the Zeppelin concept of rigid airships; he was literally compelled to fight in defense of his ideas. In 1930 it was disclosed that the British R-101, a skeletal airship, had in fact pressurized its outer hull cover made of fabric, for the purpose of holding it taut in flight and securing better drag coefficients than with loose fabric. How loose the hull fabric could be, was demonstrated by the R-100 on its arrival in Montreal, with traveling waves in the outer fabric that must have been at least five feet deep from crest to crest.

Later, in the 1960's, we learned from the WWI history of German airships, which only then was made available for the first time, that all

German skeletal airships were in fact operated as pressurized airships throughout the war, as well as afterwards. They were pressurized by lifting gas for preventing diffusion of air into Hydrogen cells; Upson advocated pressurizing of hulls by internal air acting through fabric diaphragms on the lifting gas. At lift-off, gas cells in the Zeppelins fitted tightly under gas pressure against the restraining internal wire structure of the hull even at the bottom; their airships always took off with large loads of water ballast which was gradually dumped with increasing altitude, while at the same time, Hydrogen gas was being valved, always keeping a positive pressure in the cells. In spite of inadequate means for deriving useful structural advantage from the cell pressure, at least the longerons of Zeppelin skeletal structure were partially unloaded from compressive loads by axial tension caused by pressurized cells. Without counting on it, Zeppelin airships benefited from increased hull bending strength due to cell gas pressure. This may be the reason for almost complete absence of hull structural failures in flight all through WWI, a remarkable record at that time. The fact of pressurization of Zeppelin hulls was learned by us with mixed feelings; on the one hand, a sense of gratification that it was used from the beginning and that Upson was right in spite of all villification; on the other hand, we of the Metalclad school, feel that we have been had for a long time by propaganda to the contrary. On the first flight of the Hindenburg to U. S., it was announced that the lift-off was with 38 tons of water ballast; the only conclusion that may be reached from this large ballast weight is that this airship too, was pressurized by gas and that its wartime crew was operating all airships in peacetime as they learned by experience in WWI. Due to this practice, consumption of Hydrogen by German ships during WWI was disproportionally high with respect to the displacement of their ships. In all Metalclad airships it is the air inside the hull acting against fabric diaphrams (ballonets) that is manipulated and not the lifting gas, to obtain pressure.

It should be noted that military Zeppelins were pressurized only when heavy with fuel and bombs, on their way into hostile airspace. On the way back, without load and low in fuel, they valved gas as they descended into friendly territory, at low flight speed, with gas cells limp inside the hull, and air diffusing into them, but out of danger of incendiary bullets.

The ZMC-2 hull was made of .008-.009 in. thick Alclad Aluminum alloy, specifically developed for this project, similarly as a number of other technological advancements were originated by airships. The use of Alclad spread from ZMC-2 to all heavier-than-air aircraft and made possible modern high-speed airliners. ZMC-2 hull bow and stern were assembled separately in vertical attitude, from frustum cone, ringlike sheet-metal strips riveted peripherally one to another into a continuous hull shell. Riveting was performed by an automatic machine moving below on a circular track, using three soft aluminum alloy wires which were gripped for punching holes in the sheets, then cut-off and upset into rivet heads. The seams were sealed by specially composed thin bitumastic sealant, drawn into the seam by capillary force, with a subsequent overlay of thick bitumastic on the inner side of the seam, sealing the rivet heads. Final coats of Aluminum powder, suspended in a liquid carrier were applied over the seam internally as well as externally. At that time, these seams had never been found leaking Helium in numerous tests by the most sensitive leak detectors. Now, after half a century, the sealant from the dismantled ZMC-2 is still plastic and recovers from locally imposed deformations.

The hull stern and bow were subsequently leveled into horizontal position and brought together for splicing at the maximum diameter station; the final splicing seam was performed by hand. The hull then was inflated with carbon dioxide, expelling all air through the top of the hull; next, heavy carbon dioxide was in turn expelled from the bottom by Helium arriving at the top. Mixing of gases was negligible and the hull was filled with high-purity Helium. In future Metalclad airships, cell diaphragms will allow very simple and rapid inflation procedure and also will not involve even the least contamination of the lifting gas.

Inside the ZMC-2 hull shell were perimetral frames for distributing imposed loads into the shell skin as shear, 24 longerons and intermediate frames for stabilizing them when the hull was deflated. ZMC-2 was a rigid airship, the smallest of its species, completely competent to sustain its own weight loads, without inflation with lift gas. With lift gas, but without superimposed pressure, it would have been capable of flight at reduced speed, at least half of its full speed; its maximum speed was 70 mph.

A great amount of research effort went into the preparation for its design and construction. A water model was built and tested, as well as wind-tunnel test models; corrosion exposure tests were run continuously; lightning tests were simulated; girders and their joints designed and tested; seams developed, etc. This prior work paid off generously later on; there were no "bugs" to get out of the ship, no failures or malfunctions.

Pressure control was by means of two rubber fabric ballonets with scoops for air intake during flight. Upson designed an aerodynamic control system of eight equally spaced fins instead of four as in most prior airships. His purpose was to achieve more effective stability by smaller fin surfaces. This he did by designing fins of high aspect ratio, reaching into the streamline flow field away from the boundary layer that made the fin areas nearest the hull ineffective. His additional aim was to load the hull frames supporting the fins at twice as many stations with much smaller imposed loads, a design stratagem which resulted in light fins as well as hull frames. His fin system proved to be very effective in spite of the small fineness ratio of the hull and relatively far forward location of the fins. ZMC-2 was highly controllable; it had a roll in flight, but this was due to the same sense of rotation of the two propeller slip-streams as they reached two rudder fins. Opposite sense of rotation of the engines would have cured this tendency completely.

Experience with the ZMC-2 was throughout positive and encouraging. Even before this first Metalclad airship flew, engineering work was commenced on larger airships. After the success of ZMC-2, the organization changed its name to Metalclad Airship Corporation, with pride and confidence in its mission. Several sizes of airships were studied, viz., MC-12, MC-38, MC-50, MC-74 and MC-100. Out of these studies emerged the MC-38 as the most appropriate size to be constructed, a 3.8 million cu. ft. lift hull, fineness ratio of 4.5, of 100 tons gross lift with maximum speed of 100 mph at 5,000 ft. altitude. Considerable effort was devoted to preparatory engineering and testing of wind tunnel models and detail structural designs with vast in-depth analysis, at that time still without computers. The most serious problem was the power plants, due to their low unit power, poor dependability, high fuel consumption and excessive weight. Under this stimulus were studied steam turbines, with condensers inside the hull. These ideas developed into concepts of thermodynamic management of lift of airships and other advanced ideas on what Metalclad airships should be and could do even at that time, now more than forty years ago. The depression and continuing disasters of large skeletal rigid airships at that time, undeservedly frustrated all further hopes until present times.

In retrospect it is justified and fair to say that the last five large fabric-covered airships should not have been built; their construction and operation around 1930, demanded performances which could not then be met, due in greater part to the faulty principles on which they were designed and in part also to the nonexisting diversity of technologies at that time, needed for their success. The paradox is that they were both, behind and ahead of their time; behind, due to the primitive design concepts that were demonstrated during WWI to have been unsuitable for further development. Continued construction of skeletal airships after WWI was driven by the momentum of what appeared to have been their successful performance during WWI. It was not recognized that war-time airships were much smaller in displacement than the five large ships built around 1930, and that their war performance was to be credited largely to the superbly trained, self-disciplined and responsible German crews which also operated all post-war Zeppelins. Disregarded was the fact that the losses of Zeppelins due to noncombat causes were too high, in spite of the excellence of their crews, to be acceptable in peacetime.

Large airships of 40 or so years ago were also prematurely ahead of their time in what was expected of them and they could not fulfill; they were hindered by then still inadequate technology; by too heavy power plants; still inferior metals; nonexistence of electronics; poor controls, especially at landing, poor communication means, etc. Most importantly, the principles of their design were no longer adequate and incapable of improvement without complete departure toward new and more rational concepts. This is exactly what Upson and Fritsche accomplished and what all others were unable to comprehend. Paramount weakness of all skeletal airships was their incredibly inadequate containment of the lifting gas by only one layer of thin, flimsy fabric alone, exposed to menacing bracing wires holding the cells; they suffered also from other major frailties, taken up later on.

Metalclad Principles Fifty Years Later

Now, fifty years down the stream of time, the state of the world is very different from early thirties; technology has advanced immensely in all directions and provided us with everything we might desire for rational airship construction and operation. While airplanes created a new mode of living, it has not been all to the good; they also helped destroy the railroads and nearly did away with ocean travel. Their ravenous fuel consumption has become a national burden. While airplanes fly at a minimum 500 mph between continents, the next available lower speed is at most, only 25 mph; all our mail without expensive stamps takes at least five weeks across the Atlantic; as long as in the days of sailing ships.

Airplanes are highly energy-intensive, expensive and humanly unattractive as means for long distance travel. It is now certain beyond any controversy that all modern jet transports cannot operate without taxpayers' subsidy. Airships are energy-conserving and ecologically tolerable even at 150 mph and hopefully higher speeds in the future; they are humanly highly attractive for travel. Also, new and urgent needs have developed for airships; among them the neglected necessity for surveillance of oceans, both military and nonmilitary. These new objectives give us for the first time, a sensible and legitimate reason for governmental recognition and initial support of an airship program on behalf of several national interests.

There are many such objectives; we are the world's largest producer of transport heavier-than-air aircraft of all types and it is only prudent from all national as well as business considerations, to become also the builder of airships. This extension of our industrial capabilities will have stabilizing influence on all our industrial economy, domestic as well as international. New and stable employment will be provided for many; overcongested airports will be relieved; multibillion dollar airship airports will not be required; harbors and abandoned railroad yards can be conveniently used, many of them almost ideally located as airship terminals. Hangars or docks will be needed only for overhaul. The national transport problem will be alleviated, economy enriched; all transoceanic container traffic can go by airships. Later on, airships will develop exploratory tourist travel to parts of the world not now accessible to the travelling public, such as flights along the Himalayas; over the Amazon Valley; over the North Pole; into Antarctica, visiting the Bristol Rock; etc., to no end of imagination. Airships will become an important part of national economy and culture.

It is in order to return to Metalclad airships and outline their progress, so far only on paper, through one half of a century. This progress has been considerable and was determined by two principal influences, viz., the in-depth growth of our technologies and the lessons of operation of German airships during WWI. The perfection of already existing as well as the creation of new technologies through the last fifty years, has had the most profound effect on the continuing development of design of Metalclad airships. Two basic advancements have emerged with powerful influence on the reduction of weight; one is the already established existence of light-weight, fuel-economical, high unit output, reliable gas turbines for propulsion; second is the production availability of the 7000 series of Alclads, high strength, tough Aluminum alloys now in general use in airplane construction. These alloys are particularly effective in reducing the hull weight of Metalclad airships because their strength in tension and in shear is the highest of all light alloys. Large Metalclad airship design studies of the past always concluded with favorable λ (λ= weight empty/total lift) ratios, even with older established but not as strong alloys. Now light power plants and metals drastically reduce the λ values of all future Metalclad airships. In general, it can be said that a modern projected Metalclad airship with Helium gas is superior in useful lift to a comparable Metalclad airship of 1930, of the same strength and speed but lifted with Hydrogen. Therefore, modern power plants, metals as well as other materials, have given us means to more than compensate for the lower lift of Helium with respect to Hydrogen. This fact alone is the major incentive for initiation of an airship program because due to these two powerful inputs of modern technology, the airship now can become an economical transport vehicle with a safe lifting gas.

Hulls of modern Metalclad airships will be designed with simplicity and highest possible weight effectiveness. All past rigid airships, including the ZMC-2, had their structure made up of intersecting girders, requiring nodal structural joints, too numerous to be counted. The girders were light but also easily vulnerable to human contact and their joints were not only heavy but always suspect of weaknesses, frequently proven to be justified. That was before the development of cellular structures. Thanks to it and its principles, it is now within our skill to design simple structures using cellular or honeycomb elements not sensitive to local damage, joined together by seams instead at concentrated nodal points. Cellular construction will give freedom to design transverse frames as single, deep, hollow, continuous perimetral girders, light, rigid and redundant to damage beyond hopes of the past. It also will reinforce the hull shell skin around openings, propellers and at all stations requiring local rigidity.

The longerons of Metalclad hulls will be placed externally, as continuous girders with smooth, thin but solid walls, stabilized by inner cellular matrix. There will be no specific joints between interrupted and rejoined main girders, because the frames and the longerons will overlap and bypass one another, frames inside the hull and longerons outside, with the hull shell plating between them acting as local joining gussets. Without explicit joints, the structure of the hull will be assembled more securely and simply than could be possible with the orthodox intersecting structures. This new system of Metalclad hull construction will not only be considerably lighter, but also easier to fabricate and assemble more rapidly than orthodox girder structures. External placement of longerons will increase the drag coefficient of the hull by only a little over 4%, a small price to pay for structural lightness and security, especially in view of large drag reductions from other causes, noted later on. Equally as important is the low cost of this structure without the least infringement on its quality. A simple and flexible method of fabrication of all components and their assembly into a Metalclad hull, has been developed for all sizes of airships. It is really a methodical process of the proverbial organized production assembly line using patented procedures. The total manufacturing and assembly time will be reduced to a fraction of what used to be costly and hazardous methods employed in the construction of skeletal fabric airships. This simple construction method is based on progressive modular subassembly which will not only reduce the cost, but also insure high quality throughout the process; besides, it will reduce the construction hazards to life, by eliminating multistory scaffolding, ladders and workers suspended from overhead beams in bosun's chairs. It will involve low risk to human life and provide working conditions which will lead to high productivity, quality and reliability. Metalclad airships will be precision structures of low cost due to design principles and construction techniques.

In recent years, much contemplation and thought has been devoted by us to the resumption of Metalclad airship construction. The MC-38 of 1930, was reconsidered and again recognized as the best size to commence with in our times. This conclusion was not arrived at hastily; an airship of initially approximately 100 tons gross weight at 5,000 ft. altitude operating ceiling, a modern MC-38A, is nevertheless, a size within our present design and construction competence and capabilities, besides being also of immediate practical value in oceanic surveillance, for training operating crews and for use in emergencies. Although it is an interim size, many, perhaps one hundred, might be built, also for sale to states that now buy frigates for the same purpose. It would be followed by a larger, highly useful size for unsubsidized commercial service, probably the MC-100 class.

Creation of an airship is a demanding task on human intellect, requiring meticulous concentration on details as well as on overall concepts. The basic fact is that the lift of an airship is nearly proportional to its volume, while its weight is a little more than a direct function of its surface. The most desirable form to meet these relations best, is a streamline body of revolution. Airships in this most functional form, familiar from the past, are majestic bodies; one is tempted to say that they represent creative art in its greatest simplicity and perfection. They will be also superb technical achievements because within their elegant appearance will be integrated in harmony all mankind's technological ingenuity.

In recent years have emerged several proposals for future airships without a functional justification for their form of hull, as well as for other of their features. Some of them are conceived as hybrids, deriving their lift from a lifting gas as well as from forward speed as airplanes. An airship is a buoyant vehicle and its inherent ability to stand still in its environment is one of its basic assets, not to be surrendered for some secondary gains; it is an extremely valuable quality. It will permit for instance, zero speed before and during landing and lift-off; or during a rescue operation; in surveillance work, an airship will be able to extend its flight endurance by a factor of at least 4 to 5, periodically stopping the propulsion turbines and drifting, restarting them only to change geographical station; yet, at moment's notice, it will always be capable to proceed at more than 100 mph to a suspect location.

MC-38A will be an uncommonly light weight airship for its size and speed, probably not weighing over 55.35 tons empty, including all operational equipment; 45.29 tons will be the useful load. In subsequently larger airships, the relative weight empty is going to decline at first steeply, then gradually with increasing size and is expected to reach approximately 35% of the gross lift in the MC-250 class of 675 tons gross lift. MC-38A will have all means for management of lift and flight control that are needed for safe and dependable operation of airships. No gradualism should be tolerated in introducing these means, because such a policy is more dangerous than developmental failures of individual devices. In the resumption of a comprehensive airship program, MC-38A is to be the laboratory for flight training, thermodynamic management of lift, power plants, controls, structural improvements, materials, ground handling, development of airship containers and their manipulation, exploration of coping with failures and damages, etc., to almost no end of pragmatic learning before larger airships should be built.

In all Helium-lifted airships, thermodynamic management of lift must have a prime consideration. In this regard, as in many others, we have to give thanks to the experience gained by German crews during WWI. An airship is a thermodynamic engine. When it rises, the gas in it expands and also cools. When it sinks, the gas warms up through its whole volume, resulting in superheat, and resists sinking. All volumetric changes are accommodated by cell diaphragms or walls, with respect to the internal air volume in the hull. In the past, airships were often lifted by rising air currents to high altitudes, causing heavy valving of the gas and loss of lift. Unable to stay up statically, at times they were additionally forced down by sinking currents to the ground or worse, into the sea. Also, temperature inversion often plagued airship operations.

Lift management means either heating or cooling the lift gas in at least major cells to conserve Helium and also, primarily to control the airship itself during some otherwise dangerous changes of altitude caused by weather conditions and unwanted loss of heat or gain of superheat from the sun. Internally, a Metalclad hull may be surfaced with a layer of closed cell synthetic foam to extend the time interval of development of such occurrences.

Thermodynamic management of lift will be provided by blowers driving heat exchangers in several gas cells. The heat exchangers will either receive heat from fuel combustion during sinking motion of the airship, warming the lifting gas, while at the same time also consuming fuel and lightening the load or the heat will be removed by a cooling gas cycle during a rising motion. The former case is more critical and the measures against it are highly effective and rapid in response. The latter case, cooling of the lifting gas, is less effective but also less critical.

Complementary addition to thermodynamic control will be thrustors, capable of supplementing it by generated forces on the hull. Both of these means will be used together in all cases of undesired changes of altitude.

Thrustors also will provide steering forces for Metalclad airships in altitude and direction. It will be a safer, more responsive control system not only in flight but particularly at lift-off and landing which will provide complete and firm control at standstill and near the ground, never before available. Thrustors will make piloting simpler and safer; this may be illustrated by the accident which lead to destruction of the U. S. Navy Akron. The ship was in a storm; through an opening in the clouds it was noticed that it was too close to water over offshore Atlantic. A command was given "up ship" to increase altitude. With movable elevators, "up ship" really meant "down the stern" and the lower dorsal fin dipped into the sea causing initial harm; with thrustors, the command will mean exactly what will take place, "up bow", without appreciable dipping of the stern.

Thrustors are emerging as the most important control device for airships. Again, German experience reveals a most astonishing fact of airship flights in WWI, viz., that fins and movable control surfaces of airships, useless at standstill, were undependable and at times completely ineffective in turbulent weather. Airships used to behave like free balloons, without any control whatever. Recognition of this fact lead to complete abandonment of fins and movable control sufaces for the MC-38A, entrusting the control to thrustors. A thrustor is a compressor capable of rapidly providing pressure air which in turn is expanded through a nozzle, creating a momentum force, in this case normal to the longitudinal axis of the airship. Thrustors are intended to be fixed in direction, although a gimballed movement may be advantageous in future experience. Thrustors cannot run all the time at or near their full speed with gates, due to fuel conservation. Instead, they are projected as compressors running at very low idling speed, exerting almost zero force, but ready to speed up within one or only a little over one second, to full speed, generate a high controlling thrust and slow down as rapidly back to idling when not needed. Such rapid acceleration and deceleration is possible only with contra-rotating (CR) turbomachines. Theoretically, a CR compressor can accelerate eight times faster than a single-rotating (SR) compressor of the same output; in practical application, this will be somewhat below eight times, but still more than adequate. Thrustors will be deployed on one main frame in the bow and another in the stern, on top, on port and starboard side and on the bottom of the hull. For MC-38A, at this time, a total of twenty thrustors are projected, each with maximum thrust of 1,000 lbs, eight aiming downward. Being CR machines, driven electrically, modulated for speed by high frequency system without gears, they will be very light in weight, collectively only a small fraction of the weight of the fins they displace and the water ballast they eliminate. Reliability of the thrustors will be greater than of controls with movable surfaces; the latter have a bad reputation in airships. In normal programmed flight, respective thrustors will be controlled by accelerometers with captain's override. Metalclad airships will not carry ballast but in the beginning, emergency Jato bottles will be installed, only as a precaution.

Projected Metalclad airships will fly at speeds of over 100 mph (MC-38A), later at higher speeds, perhaps 200 mph of the MC-250 class. It is therefore, natural that reduction of hull drag is of paramount importance. Abandonment of fins will reduce drag substantially; the next source of high drag is the buildup of boundary layer (BL) along the hull surface, commencing near the maximum hull diameter. Removal of the BL can either reduce the drag or permit a more full stern envelope curve, providing more lift where it has always been inadequate; or in a judicious design compromise, both of these valuable improvements may be achieved to some degree. Experience with removal of BL in turbomachines at lower and less favorable Reynolds' number than of airships, is so encouraging, even startling, that its use in Metalclad airships is regarded as indispensable. Metalclad airships will have compound curvature all over the hull, obtained by stretching originally flat metal sheets on machines now available in aircraft factories. These machines will produce hull curved metal skin in elements that will fit between two adjacent frames and two adjacent longerons; such hull surface elements are called gores. The individual gores will be attached by seams to transverse frames and longerons, thus building up a Metalclad hull, unlike the ZMC-2, which had a contour broken down into straight sequential short distances. With a mathematically perfect hull envelope curvature, having first and second derivatives also on fluent curves without discontinuities, the Metalclad hull drag will be brought to near the tunnel test values of hull models. The BL control is expected to be highly effective on Metalclad hulls with low expenditure of power, unlike on fabric-covered airships. The plating will be perforated along the perimeter of several main frames of the MC-38A, and the perforations will be manifolded to suction air pumps. The BL will not be completely removed over the whole aft part of the hull surface, but only at several stations. Power required for BL removal will be relatively small for the gains obtained. To overcome manifold losses, the suction must be sufficiently powerful and once more, the CR compressors are the only turbomachines capable of providing suction intake pressure of at least 8 psi absolute in standard air at sea level; therefore, a suction pressure difference of approximately 6.7 psi.

Planning for future Metalclad airships leads to the discovery of importance of turbomachines in their functional operation. This was not expected and yet, it is not surprising, because a turbomachine can best manipulate air and gas; turbomachines and not Diesel engines will also drive future airships; the fuel rate of modern gas turbines is now approaching that of high-speed Diesel engines of equivalent power and by the time the first MC-38A may be built, the two will be equal, with the Diesel at least 10 to 15 times heavier, not to mention excessive structural weight to support such heavy, vibrating engines. There is no Diesel engine in existence today from which an airship version could be developed; yet we often hear of intentions of driving airships by piston engines.

Propulsion turbines will be SR, derived from excellent types now in production, as also will be the central electric power system gas turbines. Elevated frequency alternators and motors will contain minimal amounts of iron and copper and the driving gas turbines will run almost always at or near full power, therefore, at maximum efficiency.

The problem of lift equilibrium with diminishing load of fuel was solved in the past, either by valving Hydrogen, or by condensation of engine exhaust into water of equivalent total weight as the used fuel, to save Helium. The latter method is not practical with gas turbines and would be rejected anyway, because of its weight, drag and complexity of installation. Instead, the inverse of water recovery is projected, which utilizes Hydrogen as supplementary fuel to the liquid fuel; in effect, Hydrogen as fuel gas lifts all the liquid fuel and is used together with it at a corresponding rate at which the liquid fuel is being consumed; lift equilibrium is never disturbed. Numerically, it means that approximately 83% of the total heat value of both fuels is in liquid form, the rest being Hydrogen. This method requires no special bulky devices, offers no additional drag, no dual tankage, only the additional weight of Hydrogen cell fabric, a relatively small amount. Hydrogen is contained in separate special cells, submerged in Helium cells. This is a perfectly dependable and safe method as was found more than 50 years ago in Metalclad research; Hydrogen as fuel is no more risky than other fuels and in some respects, less so.

All cell diaphragms are projected as made of silk, surfaced with Mylar. Mylar has approximately 100 times smaller permeability to Helium than the gold-beaters' skin fabric used in prior airships. In metal hulls it is probable that no purification of gas or its replenishment will be needed through the whole period between complete inspections and major servicing.

Metalclad Principles Compared with Fabric-Covered Rigid Airships

Fifty years later, it is appropriate and useful to conclude with this comparison because the popular impression still persists that a large airship must be fabric covered and called the Zeppelin. Before final commitment, future airship programs must be well considered and based on rigorous recognition of and respect for the past history and for facts. In what follows, comparisons are made between the Zeppelin and the Metalclad system.

Secure gas containment in airships is of primary importance. Zeppelin contains lifting gas by a single layer of fabric, no more than .007 in. thick; at best, it is only marginal. Metalclad hull contains it by a metal shell skin, in MC-38A on the average, .0115 in. thick. The former, (Zeppelin) is highly vulnerable from minor, secondary causes; the latter, (Metalclad) is not vulnerable from such causes. Dr. H. Eckner testified that in his estimate, a stern cell of the Hindenburg was probably ripped by a retaining wire immediately before the conflagration. Some of the crew heard the familiar snap of a bracing wire. It is most likely that the R-101 disaster was caused by a similar, secondary fault, resulting in irrevocable, terminal catastrophy.

-Zeppelin hull is a girder skeleton, fabric covered, with each girder on its own in the space, without stabilizing restraints of shell skin under pressure and compound tension as in the Metalclad system. Zeppelin structure is highly insecure, as the disaster of the U. S. Macon demonstrated.

-Zeppelin system does not use gas pressure to structural advantages as the Metalclad system does. Gas pressure imposes additional complexity and weight on a skeletal hull; strength as well as rigidity is derived from it only incidentally, while local structural stability is reduced. Zeppelin structure is loaded in compression and bending; Metalclad structure is loaded in tension and in shear, directly utilizing the metal to best advantage. Zeppelin skeletal structure can use modern high strength alloys with only small advantage. When a structural girder is in bending or compression, the principal strength parameter is its form factor and not the strength of metal. Fifty years ago, the total structural weights of both systems were comparable. Today, modern high strength, tough light alloys have turned this comparison in favor of Metalclad construction so dramatically, that the economic viability of Metalclad airships is assured.

-The Zeppelin hull contains along its whole internal surface, a non-lifting airspace; in R-100, it was three feet deep. This space amounts in fact, to a major reduction of lifting volume of all fabric covered skeletal airships, significantly adverse to their economic merit. Experience shows that this space is not effective in preventing superheat, particularly during descent. Metalclad airships use the whole hull displacement for lift at ceiling altitude. This difference in lift amounts to the second large relative gain in load carrying capability of Metalclad over Zeppelin airships and is in itself highly important to the economy of airship operations.

-Zeppelin structure is complex, expensive and requires extensive rigging and rerigging. It is heavy with joints; in case of cell deflation, the fabric of the cell will sink to the bottom and the hull will be weakened. Metalclad airship structure is simple, requiring minimal number of joints. It is highly efficient in carrying loads, yet redundant to damage, while the Zeppelin structure is sensitive to damage and its margin of redundancy is low in spite of its complexity. In case of loss of lifting gas in a Metalclad cell, the air pressure will lift the cell diaphragm and press it against the inside of the hull shell and keep on maintaining pressure in the hull.

-The top of all lifting gas cells is subject to the highest pressure. In Zeppelin cells, this pressure is resisted only by the cell diaphragm with respect to external air. In Metalclad airships, the metal shell contains this pressure and leakage is practically zero, compared to higher rate through a fabric cell wall under pressure. The lower part of all cells is directly comparable in both cases, because pressure on both fabric sides is the same.

-Zeppelin cells are exposed to a high wear rate, due to continuous chafing in flight, especially with surging lift gas. There is next to no wear on cell diaphragms in Metalclad airships.

-Zeppelin hull fabric cover and the fabric of its cells absorb large amounts of water in rain and in high humidity atmosphere. Metalclad airships are immune to this.

-Fabric covered skeletal airships will not be able to achieve high speeds of flight. Metalclad airships, being pressurized and having all-metal hulls, will be capable of 200 mph speed in large sizes of the future. Fabric covered hulls suffer deterioration under tropical sun; fabric becomes loose on their skeletal structure, sags and impairs aerodynamic efficiency. At times it tears in flight and endangers the safety of the airship, as occurred on one transatlantic flight of the Graf Zeppelin.

Controlled by thrustors, Metalclad airships will be docile in handling, not only in flight but also near the ground, requiring only a few men to anchor to a mast and tractors. They will always be under full control even in cross winds at standstill. They will not be fragile; on the contrary, if prudence may indicate it, the captain will have the freedom of increasing the hull pressure beyond the maximum value required to meet the highest aerodynamic moment by a factor of four in the case of MC-38A, still within 80% of the yield point of the metal; for practical reasons, Metalclad airship of MC-38A size will be built with thicker hull skin than needed; all Metalclad airships up to approximately MC-50 will be in fact, overdesigned in structural strength and weight. The full light weight potential of Metalclad airships will come into effect in the MC-100 class. Although the relative weight of hull plating will decrease with size, the hull pressure and the strength of even the largest Metalclad airships will be more than sufficient to cope with all weather and landing conditions.

Metalclad airships will have built-in, replaceable containers, capable of lowering onto the ground; these freight containers may be constructed for liquids, dry goods, may be refrigerated, or designed as habitable quarters, or fitted with electronic gear for testing during flight, etc. Some airships will have hulls with internal understructures for holding heavy unit loads for long distance transport to inaccessible places.

From the very beginning, Metalclad principles brought into the development of buoyant vehicles new concepts that demonstrated, even in the small ZMC-2, that airships can be sturdy, safe and weather-independent, reliable and an economical means of transport. The application of modern technologies to Metalclad airships assures beyond doubt that these qualities can become permanent characteristics of these airships. Metalclad airships can now be designed and constructed with full confidence in the fulfillment of all expectations for them. Furthermore, they can be constructed rapidly and economically, at costs no greater than the costs of hulls of ocean tankers of comparable dimensions. By way of comparison, even the largest Metalclad airship of the MC-250 class, so far only imagined, would be shorter in length by some 200 ft than a typical 240,000 ton tanker, many of which are now on the high seas.

Automation as well as high useful lift/weight ratios and low energy requirements will be the basis of low operating costs of Metalclad airships, not to mention low insurance rates, earned by their reliability.

Now, on the threshold of the third century of our history, the continuation of the development of Metalclad airships is a challenge to our national pride as well as to our economic well-being and future security in every manifold diversity of this word. The Metalclad concept was developed in our country and we owe it to our collective conscience to see it brought to the state of usefulness to ourselves and to the whole world.