DOCUMENT RESUME

ED 031 064 EF 003 541

By-Robertson, Nan
Air Structures for School Sports.
Educational Facilities Labs., Inc., New York, N.Y.
Pub Date May 64
Note-28p.
EDRS Price MF-$0.25 HC-$1.50
Descriptors-*Air Structures, Athletic Activities, Construction Costs, Costs, Maintenance, *Physical Education Facilities, *Prefabrication, Safety, School Construction, School Maintenance, School Safety

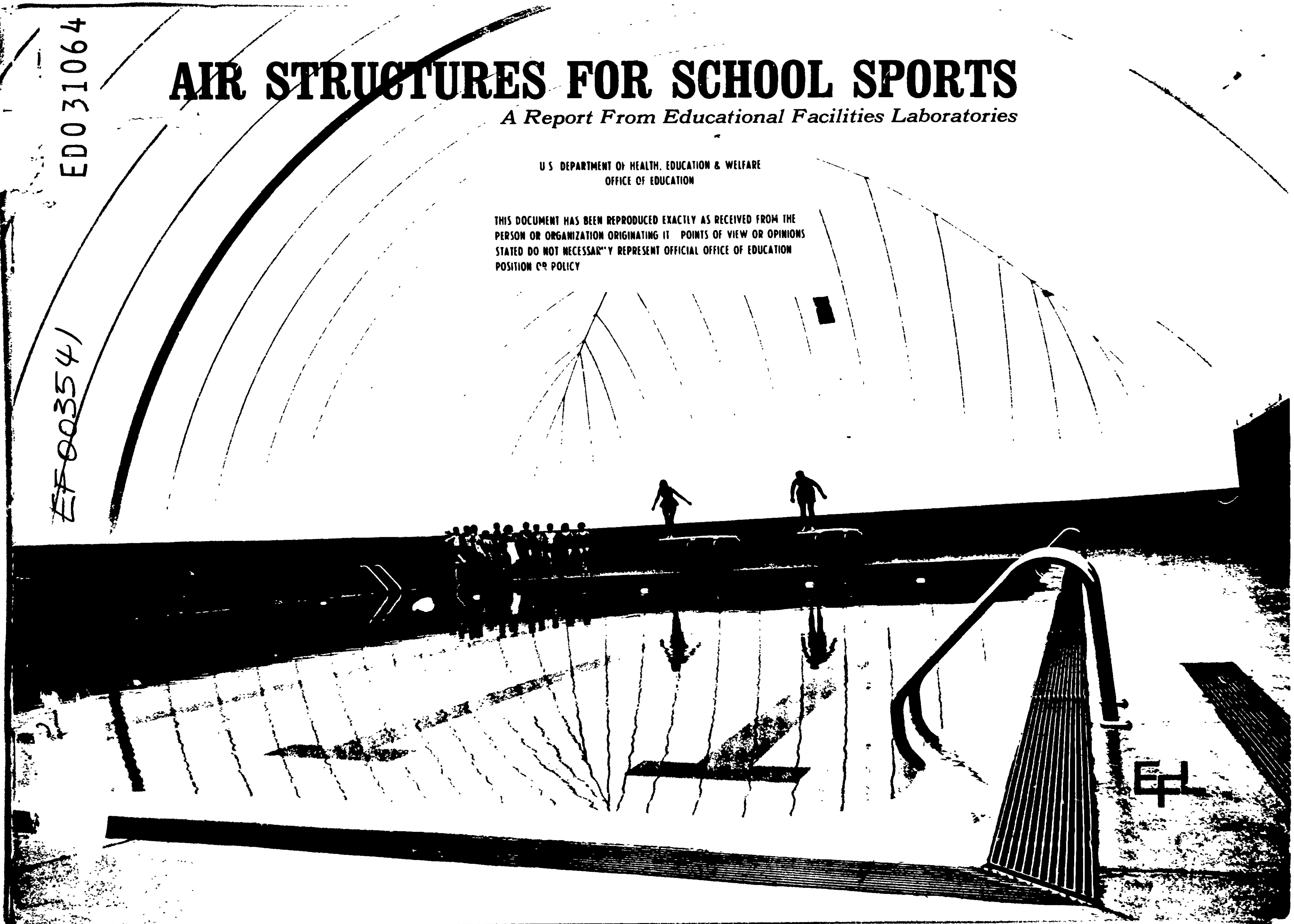
Air structures are fabric buildings blown up and held up by air pressure. Experiments with such structures were conducted as early as 1917. In 1948 the United States Air Force sought a new way of housing large radar antennae planned for the arctic. As an outcome of their search, Birdair Structures, Inc., which is now one of several companies selling such structures, was founded. Early experiences with air structures for schools in Litchfield, Connecticut, were disappointing. The subsequent erection of two more bubbles was evidence that satisfaction was eventually achieved. Cost estimates of $2.14 per square foot compare favorably with wood-domed fieldhouses at $6.53 per square foot or geodesic fieldhouses at $8.34 per square foot. Costs for swimming pool use are estimated at $9.38 per square foot as compared to $26.00 and $32.00. Ease of heating is also emphasized. Installation time is approximately one day. There is no danger of suffocation in case of deflation because the process is slow and the material can easily be lifted should one find it necessary to get out under such conditions. There is no fire danger. Because of high reflection surface, lightning problems are minimal. This document previously announced as ED 018 924. (RH)

ED031064

EF003541

AIR STRUCTURES FOR SCHOOL SPORTS

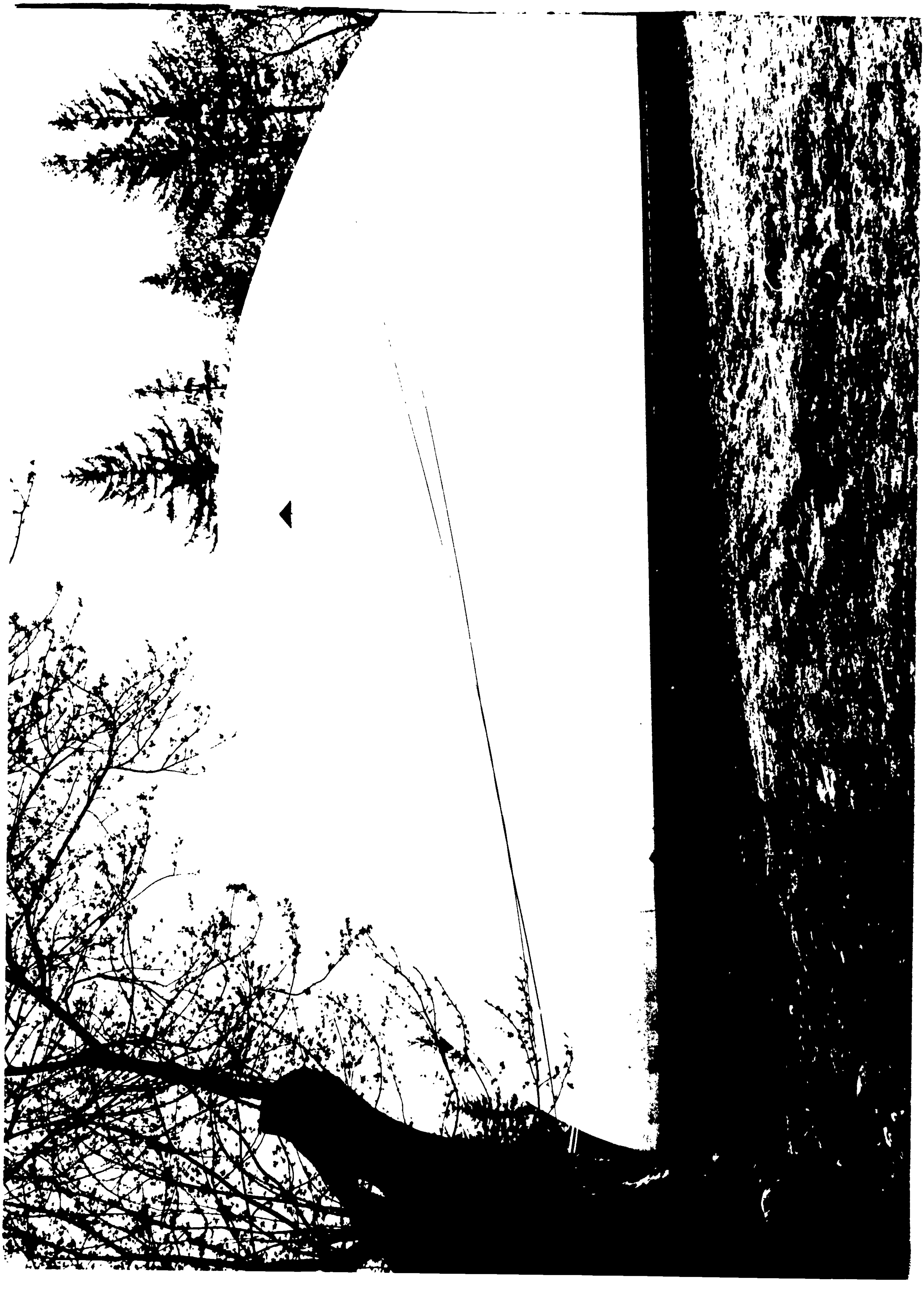
A Report From Educational Facilities Laboratories



EDUCATIONAL FACILITIES LABORATORIES, INC.
is a nonprofit corporation established by the Ford Foundation in 1958 to help American schools and colleges with their physical problems by the encouragement of research and experimentation and the dissemination of knowledge regarding educational facilities.

AIR STRUCTURES FOR SCHOOL SPORTS

A Report From Educational Facilities Laboratories by Nan Robertson



FOREWORD

AIR STRUCTURES — buildings blown up and held up by air pressure — were introduced only 10 years ago, but they have since proved themselves in a variety of applications. The military, which sponsored their development as radar stations, also uses them as supply depots and even as hangars. Industry uses them for warehouses. Resort hotels and private athletic clubs use them as cold-weather covers for outdoor swimming pools and tennis courts. Participants in the New York World's Fair will use them to house exhibits. A giant bubble outside Chicago is used as a stadium for sports events ranging from ice hockey to wrestling.

In each case, the air structure's feature attraction is its ability to enclose large areas quickly and cheaply. The basic structural envelope — a skin that serves as both walls and roof, plus attachment hardware to hold the structure down and inflation equipment to hold it up — costs under $2.00 a square foot. It can be anchored in place, blown up, and readied for use in a day. In even less time, it can be deflated, freed from its moorings, folded like a tent, and stored or moved to another site. Safe and easy to care for, it will last at least five years in continuous service, twice that if used only part of each year or treated to a factory reconditioning.

Because of its economy and versatility, the air structure fits neatly into many schools' specifications for physical education facilities. But until 1961, schools merely contemplated the bubble from a distance.

That spring, The Forman School of Litchfield, Connecticut, shook off the blanket of snow that had engulfed its campus all winter, making outdoor play all but impossible. Its need for all-weather athletic facilities effectively underlined, Forman cast about for an inexpensive way of providing enclosed play space. It came up with the air structure, which looked promising enough to justify a bit of trail blazing. The bubble had, after all, been used for sports before. Using it for school sports should not pose serious problems.

So Forman, backed by a grant from EFL, commissioned The Architects Collaborative to study the pros and cons of air structures, and rule on the feasibility of using them to house its proposed indoor sports facilities. At the same time, the school began conducting its own on-the-spot experiments with a practice bubble launched over an existing tennis court.

This first bubble did pose serious problems. Twice, it collapsed altogether. But the architects' investigations, additional EFL-supported studies of special difficulties with heating and lighting, and Forman's practical experience finally paid off. By the fall of 1963, two years after the trial balloon went up, Forman was the proud possessor of two smoothly functioning air structures — one over a swimming pool, the other over a tennis court that doubles as a gym.

The Forman School's adventures with bubble-covered play space, described in this report, show that well-designed air structures can be reliable and practical enclosures for physical education. But the Forman chapter is the beginning of the story, not the end.

Other schools, drawing on Forman's experience, are now approaching air structures with the confidence that comes from knowing in advance where potential problems lurk and how to avoid them. And industry is responding to the newly opened educational market with new products and materials that will make the bubbles even more attractive to schools.

Forman's tennis court bubble, for example, is the setting of the first field test of a unique "grass" with molded vinyl plastic "blades" sprouting from square plastic tiles. Neo-Turf was originally developed by the Boston Woven Hose Company to provide a playground surface more childproof than garden-variety grass, but more welcoming than asphalt or concrete. It coincidentally provides a well-nigh perfect surface for tennis — or so say the tennis buffs who flock to the Forman court every day after school.

Of the other developments promised for the near future, perhaps the most significant are improvements in skin materials, which now limit the size and shape of air structures as well as their potential life span. By extending the present limits, stronger, longer-lasting fabrics could also extend the bubble's range of educational applications far beyond today's seasonal shelters for sports. — EFL

This is the story of a school — and a bubble

The school is The Forman School in Litchfield, Connecticut, which brings its outdoor sports facilities indoors for the winter by blowing bubbles over them. The first bubble pioneered the use of air structures for school athletic spaces. Pitched on top of one of Forman's tennis courts, it was also used for basketball, infield baseball practice, and other sports.

Forman's second bubble, attached on one side to a low-lying conventional building, provides winter shelter for an outdoor swimming pool, making it usable all year long. This fall, still another bubble, a permanent replacement for the first, went up over 7,200 square feet of artificial grass, the plastic equivalent of a carefully manicured golf green. The new bubble-covered playing field is designed primarily for tennis. (Permanent lines of white "grass" delineate the tennis court.) But it too is used for basketball, volleyball, and badminton by marking off the proper courts with masking tape.

The bubble is a new idea in building — a structure supported solely by air pressure, in which skin and skeleton are one. It can be quickly inflated or deflated, like a big balloon. Very slight continual pressure from blower fans will hold it up. When down, it can be folded into a compact parcel and stored, or taken to another site for reinflation. The bubble can look like a dome or a giant bratwurst sliced in half. In its simplest form, it is anchored snug to the ground like a tent with the earth serving as a floor. Its most practical skin to date has been white, translucent, vinyl-coated nylon.

The skin can roof big outdoor areas and shelter both men and things from rain, snow, wind, and bitter cold. For a decade, the U.S. Army has been using air-supported structures to house radar equipment along the Distant Early Warning line in the Arctic. Other, more recent bubbles cover the Telstar antennae in Maine and northern France, outdoor swimming pools in Atlantic City, New Jersey, and tennis courts in Norwalk, Connecticut. At least two will go up over exhibits at the 1964 New York World's Fair.

Now, schools are beginning to eye the bubble with fascination as a new way to cover space for physical education. The Forman School was the first educational institution to actually try it.

A CLIMATE FOR EXPERIMENT

Forman, which lies inside the "prep school belt" of western Connecticut, is not nearly so wealthy nor so old as other nearby prep schools — Hotchkiss, Salisbury, Choate, Taft, and Kent, to name a few. It was founded in 1930 and has 175 students on two campuses. There are 105 boys and 70 girls from the seventh through the twelfth grades. The girls lunch and go to classes with the boys on their campus, which consists of nine pretty, but modest, Colonial-style buildings in clapboard, stone, and red brick atop a hill on the edge of town. The tenth is the Commons Building, now under construction. Beside it nestles the swimming pool bubble.

The typical American prep school builds the "all-around boy," with emphasis on sports as well as study, and Forman is no exception. As devotees of the rugged life, Forman students prefer to play outdoors much of the winter — skating, skiing, and sledding. But the winter of 1960-61 forced even the Forman boys indoors. "We had snow up to our ears," recalls Stowell Mears, the school's Director of Development. Since Forman did not have a gym, basketball and other games were played at a nearby YMCA.

The school did not have a gym for two reasons. First, gymnasiums are among the more expensive facilities a school can build. Because they need long-span structures covering large areas, their minimum cost is about $200,000 — more than Forman could afford to spend. Second, Forman's former gym, long since converted to a dining hall, had been used for sports only two to three hours a day. To build a permanent gym so costly and so little used would be highly inefficient. Yet sheltered play space would be highly desirable, at least for part of the school year.

Shortly after that snowbound winter, Mr. Mears heard about air-supported structures from the father of a Forman student. The structures were not only portable, light, and fireproof, said the parent — they were cheap. A bubble big enough to cover a tennis court would cost about $10,000. It would last easily 5 to 7 years. Back to the factory for a retread, it would perform well 8 to 11 years.

It seemed that Forman had finally licked the problem of a provisional gymnasium. Mr. Mears went to a nearby supplier of air-supported structures, David P. Zamore of Montclair, New Jersey, and brought back a bubble to try out.

EVOLUTION OF A BUBBLE

Although the first experiments in roofing large areas with air-supported skins date back to 1917, it was more than 30 years before such structures became practical. In 1946, when the United States Air Force was seeking a new way of housing the large radar antennae planned for the Arctic, it came to the Cornell Aeronautical Laboratory in Buffalo, New York. The laboratory suggested an air-supported structure. For the next two years, a team directed by a young aeronautical engineer, Walter W. Bird, designed, built, and successfully tested the radome prototypes. By 1954, the military's new plastic-coated bubbles were scattered by the hundreds across the United States and Canada.

Then, in 1956, Walter Bird and a few of his colleagues struck out on their own, formed Birdair Structures, Inc., and began producing civilian bubbles. Now, there are about 40 Birdair bubbles in commercial and industrial use in the United States, plus dozens of similar structures produced by other manufacturers who have entered the field. And an industry association, the Air Structures Manufacturers and Suppliers Association, has been formed to raise and maintain standards for air-supported buildings.

But there is still widespread misunderstanding about what the bubbles can and cannot do. As Walter Bird recently pointed out: "It must be recognized by others and ourselves that further research and development are required before these structures become foolproof."

The Forman School bubbles make a significant contribution to this research and development work for several reasons:

1. They are pioneers in the educational field.
2. The first, over the tennis court, was a classic test case of an air structure exposed to unusually severe conditions, both natural and man-made.
3. Professional architects and engineers refined and perfected Stowell Mears' solutions to the problems posed by the first bubble, and incorporated them into the second bubble over the outdoor swimming pool and the third bubble over the new plastic-turfed tennis court.

The professionals were The Architects Collaborative of Cambridge, Massachusetts, who were engaged by Forman to investigate the feasibility of air-supported structures for indoor athletic facilities. The feasibility study was made possible by a grant from Educational Facilities Laboratories, which also supported later studies of the special problems that arose with lighting and heating the bubbles, and contributed to the development of the turf-floored bubble, another prototype.

On the basis of the architects' research, and its own practical experience with Bubble No. 1, Forman decided that the advantages of air-supported structures far outweighed any disadvantages. Since all the important lessons had been learned with the first bubble, it could safely proceed with Bubbles No. 2 and 3.

THE BUBBLE THAT BURST

Bubble No. 1 was beset with troubles for several reasons. To begin with, the first bubble was erected over the lowest of three tennis courts that march stairstep down a steep hill. The courts above it were frozen during the winter for a skating rink. When thaws came, water cascaded down the hill, seeping under the circular apron that lay tucked all around under the bubble, flat on the ground, and flooding the court. Mr. Mears' temporary solution to the drainage problem was to pack sandbags along the side of the bubble as a dike.

Guarding Bubble No. 1 from fierce gusts swooping down over the hill and up the narrow valley was another matter. The weekend before New Year's Day, 1963, tennis was being played inside the structure while winds officially registered at over 90 mph were raging outside. The players were unconscious of the storm. But 10 minutes after they left, the bubble began to collapse.

This does not mean that air-supported structures cannot withstand high winds. Testers at the U.S. Army Natick Laboratories, Natick, Massachusetts, have found that taut buboles can resist winds as high as 100 mph, rocking slightly with the punch. But should there be any "dimpling" of the structure because of big leaks, heavy snow loads, or insufficient air pressure, the bubble is in trouble. Fabric whiplashes will develop. If there are any sharp protrusions on equipment inside, a flabby skin may tear on them in windy weather, or rips may begin along the seams and continue uncontrollably. The bubble will then sink slowly to the ground.

The villain in the December storm at Forman was a defective door. This single door, opening outward because of Connecticut fire laws, was held closed by a simple snap lock. Before delivery, the jamb had been bowed away from the latch. There was no bolt to lock the door. This was the weak link that collapsed Bubble No. 1. A sudden gust sucked the door open and pressure fell inside. For two days, the raging storm tossed the deflated skin about on its moorings. The wounded bubble had to be sent away for repairs.

Other problems Forman encountered with Bubble No. 1 can be traced to a lack of information about the handling and operation of air-supported structures for sports. Because the application was a new one, Mr. Mears could not draw on the experience of others. He had to figure out for himself how to light the bubble properly for tennis, how to heat it, and how to protect the blowers from suffocation by heavy snowfalls.

In spite of these difficulties though, the good points of air-supported structures also emerged clearly during Forman's two winters with Bubble No. 1. These features make them appealing for campuses: They are safe and comfortable, easy to put up and take down, and durable. Above all, they are inexpensive.

THE COST PICTURE

In their feasibility study, the architects compared initial costs of a laminated wood-domed fieldhouse, a conventional gymnasium, a geodesic-domed fieldhouse, and a single-wall, air-supported structure.* Each building covered about the same gross floor area — from 31,600 to 35,800 square feet.

The cost for the wood-domed fieldhouse was $209,100 or $6.53 per square foot. The conventional gym cost $261,800 or $8.28 per square foot. The geodesic fieldhouse cost $298,400 or $8.34 per square foot. The bubble, including skin, fabrication, blower equipment, the arrowhead anchors and cables that fix it to the ground, and auxiliary power, came to $74,200 or $2.14 per square foot.

*To permit a valid comparison, only the cost of the finished structural envelope, including daylighting, and, in the case of the air-supported structure, basic inflation equipment, was considered.

Then the architects compared costs of indoor swimming pools housed in conventional structures with the bubble-covered pool planned for the Forman School. The estimated cost of a 75 by 42 foot indoor pool proposed for Scarsdale High School, Scarsdale, New York, was $250,000 or about $26 per square foot. A slightly smaller high school pool at Uniondale, Long Island, New York, also totaled $250,000 in cost, about $32 per square foot. Forman's pool, the same size as the one proposed for Scarsdale, was built and covered for only $61,300 or $9.38 per square foot. (All costs are exclusive of showers, lockers, spectator seating, heating plant, and outside facilities.)

But initial costs are not the whole story. A second cost consideration is that bubbles are easy to heat because there is nothing but air to warm. Conventional buildings, because of their mass, need constant heating. An ordinary gymnasium, if allowed to cool off entirely during periods when it is not in use, takes a long time to reheat to the required temperature. Not so a bubble.

Mr. Mears at first used two space heaters which zoomed the temperature inside Bubble No. 1 to the desired level for sports within 5 to 10 minutes. He later abandoned these kerosene heaters, though, because they were dirty, depositing soot on the bubble skin, and noisy, their roar aggravated by the echo quality of bubbles. During the second winter, following the recommendation of heating consultants Fitzmeyer & Tocci of Boston, he substituted a high volume, low velocity, hot air furnace which brought Bubble No. 1 up to 40 degrees over outside temperature within about 15 minutes, heating it quietly and cleanly as well as quickly.

The same furnace has worked equally well in the new tennis bubble except on extremely cold days. Forman expects to try using so-called "people heaters" as a supplementary heat source during Litchfield's occasional spells of sub-zero weather. These radiant heaters warm objects in their path but not the surrounding air, so there is no time lag at all. The school also hopes to experiment with a larger furnace whose fans could double as inflation equipment, thus saving the cost of at least one blower.

Forman Bubble No. 2, which is over water, presented different heating problems from the land-based No. 1. If the bubble was not kept heated during the pool's inactive period, the water would rapidly lose its heat to the cooling air. If the water was allowed to cool, it would take a long time to heat it for pool use. For this reason the architects decided it would be better to keep both the pool and the air inside the bubble heated even when it was not in use. So heating costs for the swimming pool bubble are much higher than for a tennis court or basketball bubble, which needs no advance warm-up time.

A real cost advantage of bubbles for covering swimming pools is that air structures do not deteriorate or

Deflated, an air structure big enough to cover a tennis court rolls up into a compact, easy-to-store package.
***Below:** Swimming pool bubble is bolted to concrete ledge around pool deck, then inflated*

require expensive upkeep because of condensation. Steel will rust. Wood will mold. Paint will crack, blister, and peel. But the bubble's vinyl-coated nylon skin is unaffected by moisture, and unlike some pool covers, it does not let water that forms on the ceiling drip down on spectators or loungers by the pool. Because of the bubble's shape, most of the condensation water rolls right down the sides. All but a little of the rest should be evaporated by the air circulated from the blowers.

EASY UP, EASY DOWN

Ordinarily, it takes one day and six men to put up a bubble. At Forman, where there was unlimited boy power, the job went faster. If the bubble is to be inflated over earth, metal arrowhead anchors attached to cables are driven by jack hammers into the dirt or grass. These anchors were sunk about 3½ feet below ground. Then they are "dead-headed" — pulled to a horizontal position by another simple contrivance — and fixed to the bottom of the bubble by the upper ends of the cables, which are run through metal-reinforced holes in the bubble-skin. About 80 anchors set three feet apart held down Forman Bubble No. 1 through two winters of storms, wind, and flapping of the fabric when the bubble was partly deflated.

Another form of anchorage, used if the bubble is to be based flat on concrete, can be seen at Atlantic City swimming pools surrounded by big, outdoor sun decks. Here, Birdair runs a hollow tube through the bubble's hemline between two thicknesses of fabric. The tube and the hemline are punctuated with matching holes. Through these, bolts are run, fastening into vertical tubes that have been drilled deep into the concrete.

Other attachment conditions (and other bubble manufacturers) may call for other ways of making a fast, firm connection between the bubble and its base. The bubble over the Forman pool is bolted to the top of a concrete dike that encloses the pool deck. The new tennis court bubble, like the first, uses arrowhead anchors at the ends. At the sides, though, the cables running through the bubble's hem are attached to "deadmen" — heavy steel columns placed in long trenches — instead of to arrowhead anchors.

Anchoring is done while the bubble is deflated. Using two ½-horsepower blowers, the structure can then be blown up like a balloon. This may take from 30 minutes to 3 hours for a bubble big enough to cover a pool or tennis court. Thirty minutes to an hour is the more common experience. A longer period may mean a leak, perhaps through a bubble entrance, or the fans may not be working to capacity. Once the bubble is up, continuous air pressure from the blowers keeps it up.

The bubble is taken down by a reverse process. First it is collapsed by stopping the power and opening the door. Cables are unhitched and the bubble folded like a giant handkerchief into the smallest possible packet.

When Bubble No. 1 arrived at Forman, the huge structure was contained in a wrapped burlap package 10 feet long, 5 feet wide, and 4 feet high. When deflated and folded for storage by amateurs it was bigger — about 15 feet long and 6 feet wide. This, however, was narrow enough to be hoisted inside a truck.

THE SAFETY FACTOR

Unlike their soapy namesakes, nylon bubbles are not fragile. The vinyl-coated fabric is remarkably strong and resistant to vandalism or mishandling. For a man to tear it with a knife, he must force the knife every inch of the way. The main source of fabric weakness is the seams of the bubble skin. The seams are overlapped and heat-sealed, so they are stronger than sewn seams, but even electronically welded seams may rip if the bubble is partly deflated and lashed by high winds. Since serious rips are often started by the fabric's catching on a sharp protrusion inside the bubble, an obvious precaution is not to have sharp protrusions inside. Another might be rip stops consisting of more seams cross-hatching the original seams, as in the quilting technique used for bubbles made by the G. T. Scheldahl Company of Northfield, Minnesota.

The object in both cases is to keep little rips from becoming big ones. Because they are supported by enough pressure to compensate for some leakage through the pores of the skin, bubbles can survive a number of small

Spectators and instructors can watch pool activities in dry comfort from viewing area inside adjacent commons building

punctures. And as long as punctures or tears remain small, they can be repaired easily. This is done with a patch made from the same material, which is applied to the inside of the skin with the bubble inflated. First, a heavy coat of vinyl cement is brushed on and allowed to dry an hour. Then — a cozy, domestic touch — the patch is mated to the fabric by ironing it on with a regular home iron set at "wool," or 300 degrees Fahrenheit. During the ironing a board should be held against the spot by someone outside the bubble.

As Forman discovered on two occasions during its adventures with Bubble No. 1, bubbles can and sometimes do collapse, but they are not dangerous even when mortally wounded. In the case of power or equipment failure — which can be easily avoided by providing standby generators and blowers — the structure takes at least two hours to settle to the ground. If a large rip occurs, the bubble may go down faster but there is virtually no possibility that a person could be trapped under it for long. Anyone can walk out from under a burst bubble, lifting up the deflated skin with his hands as he goes. And according to Birdair and others with long experience with air-supported structures, the collapse of a bubble has never caused an injury.

Danger from fire is also as near zero as it can be. The bubble skin will not catch fire. Through prolonged exposure to an intense heat source, such as a nearby quartz lamp, the fabric could conceivably sizzle, and a small hole might be burnt through. If this happened, though, the pressurized air inside would rush out through the hole, snuffing out the flame as a cigarette smoker blows out a match. Extensive fire tests have been run on the bubbles by their manufacturers and the Army; the results are uniformly reassuring.

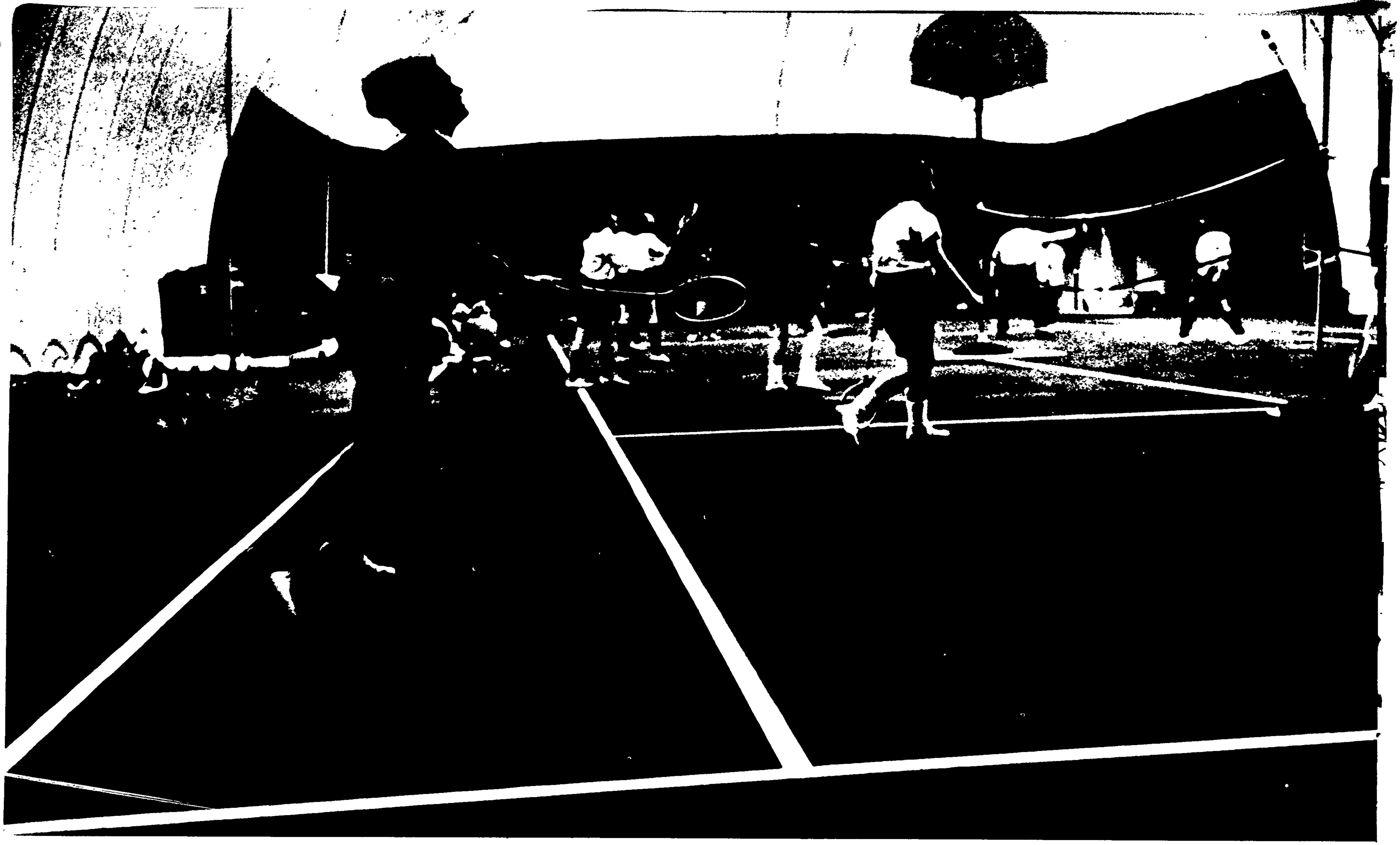
COMFORT UNDER PRESSURE

People ask: What is it like to be inside these things? Do you feel the pressure? The answer to the first question is: Like being in any building. To the second: No.

Putting it technically, air-supported buildings need only 1 inch of water static pressure to hold them up — equal to .036 pounds per square inch. In layman's language, if you close your mouth and puff out your cheeks with air, you are creating about 30 inches of water static pressure inside your mouth. An automobile tire carries about 600 inches of water static pressure.

The only time a person entering a bubble knows that air pressure is involved is when opening the door. Bubble No. 1's single door (swinging outward for safety reasons) opened easily; closing it required a stout pull. If a revolving door is used, a slight rush of air may be felt for a second. With double doors, which are much less costly than revolving doors, there is almost no air rush.

The outer of the two doors is at the end of a short, above-ground tunnel connected to the bubble. This door is closed by the person entering. The inner door,



Twelve-inch squares of artificial turf provide an ideal playing surface for tennis, badminton, and other sports. Permanent strips of white "grass" delineate tennis court

fixed to the bubble's skin, is opened only after the second door has been closed. Because they form an air lock, double doors minimize leakage and the slight psychological adjustment needed at the moment of entering a pressurized building. The obvious choice for Forman's swimming pool bubble, which adjoins a building, double doors are also used for the new tennis court bubble where the air lock had to be built on.

TOWARD BETTER BUBBLES

Low cost, minimum upkeep, fast pitching and striking, comfort, and safety. The advantages of well-designed air-supported structures can be fully realized in Forman's newer bubbles largely because the school's venture with Bubble No. 1 exposed potential trouble spots and provided a laboratory for testing ways of avoiding them. Except for its location and its artificially turfed floor, the new tennis court bubble differs very little from its now-retired predecessor as it finally evolved after two winters of study and experiment. And the bubble-covered swimming pool, which Forman began building in the midst of its early struggles with Bubble No. 1, shows clearly how the lessons learned from that trial balloon contributed to the success of its successors.

The first lesson was the importance of a suitable site. Bubble No. 1 was plagued by thaw water from the frozen tennis courts above it. The newer bubbles clustered around the commons building have no thawing tennis courts above them, and the site's natural drainage can cope with any normal flow of water.

The commons building bounds the adjacent outdoor swimming pool on one side. The pool enclosure is completed by a 4½ foot high ledge circling the deck. When the pool is brought indoors for the winter, the big bubble skin is bolted all around to this cement dike. On the building side, a concrete canopy 8 feet high and 66 feet long, paralleling the pool, juts into the bubble. Without a break, the ledge to which the bubble is fastened runs atop the canopy and down its end walls to poolside level so that the canopy links building and bubble. Under it are the double-door air locks, one for swimmers and one for spectators, that provide access to the pool. When the building is completed, swimmers will be able to pass directly from dressing rooms to the bubble-covered pool without going outside.

The bubble itself is 108 feet long, almost 68 feet wide, and about 31 feet high from pool deck level. As a perfect half-cylinder, it would have been almost 7 feet higher at its peak. But The Architects Collaborative shaved the bubble to a shallower dome for sound reasons — sound in the literal sense. The echoes produced by sound waves bouncing off the top of a half-cylinder bubble might make instructions difficult to hear. With a slightly flatter dome, the focal point of sound is pushed to below the water level of the pool and buried, but the acoustics still leave a good deal to be desired.

LIGHTING THE BUBBLES

One of Forman's worst problems with Bubble No. 1 was lighting. On sunny days, light streamed through the bubble's white, vinyl-coated nylon skin — glarefree, uniformly diffused. and bright enough to play any game by. During the winter months, though, when the sun set early, this ideal natural light began to fail by 3:30 in the afternoon even on clear days. At night, on cloudy or stormy days, on dark winter afternoons — the very times an indoor play space was most needed — artificial lighting was a must.

Mr. Mears had been led to believe that the bubble could be adequately lighted for tennis and other sports by placing floor-mounted fixtures so that their light would be reflected off the side walls. He tried it, using four 500-watt quartz lamps. This 2,000-watt trial system, which relied wholly on indirect light, greatly underestimated the power required to light a windowless bubble for night or dark day tennis.

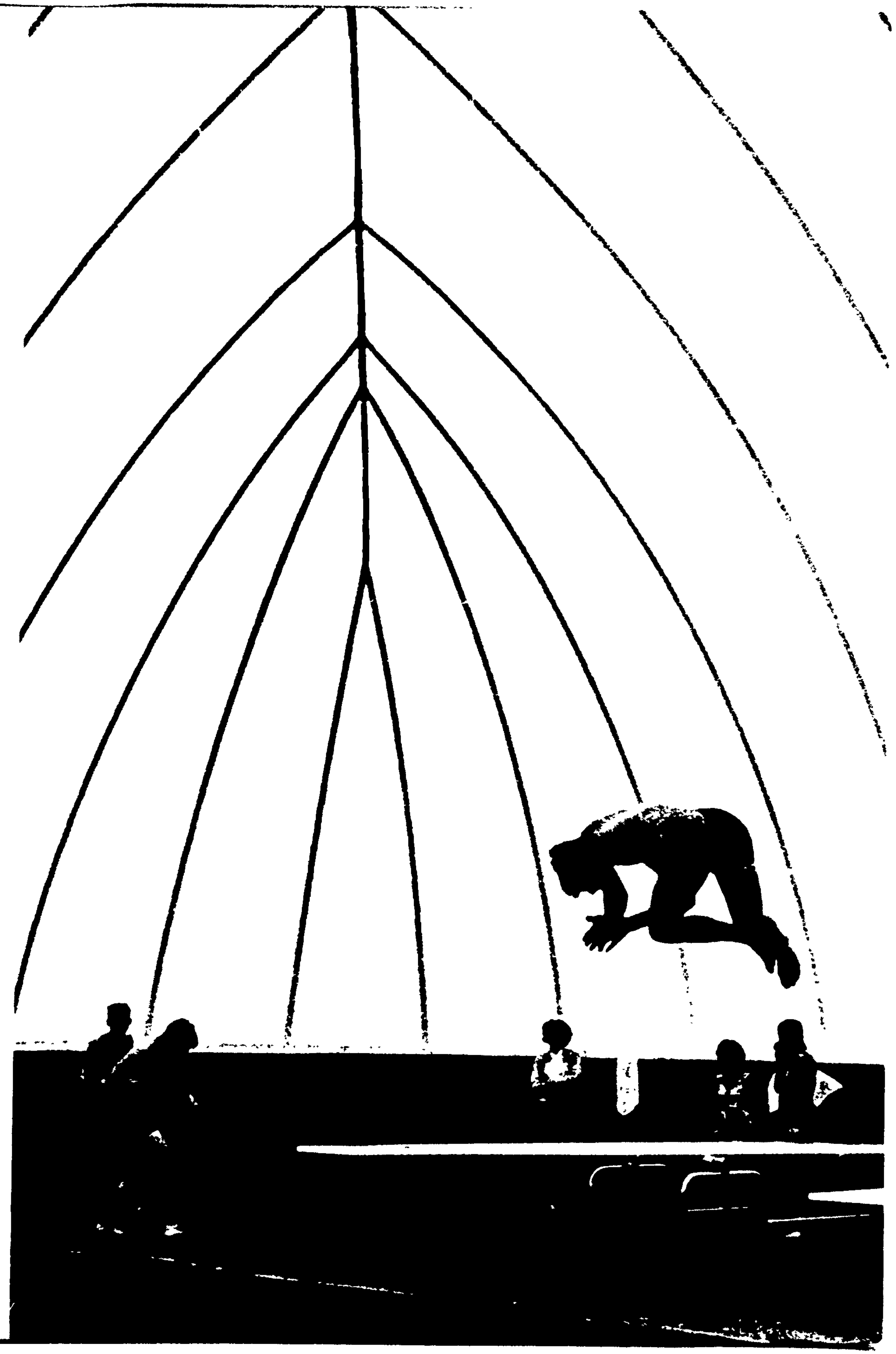
A tremendous amount of light is needed to play tennis in a bubble — much more than for basketball or swimming. This is due more to the nature of the game, however, than to the nature of the bubble. The translucent skin that lets outside light stream into the bubble on a sunny day also lets some inside light seep out of it. William C. Lam of Cambridge, Massachusetts, lighting consultant for the Forman bubble projects, estimates that the light loss through the skin is between 5 and 10 per cent. Another 20 to 25 per cent of the light striking the skin is absorbed and converted to heat. But the rest of the light — some 70 per cent — bounces off the skin to light other surfaces and objects. The bubble skin's 70 per cent reflectivity is high compared to most materials, and its 5 to 10 per cent light loss is not a critical leak if there is enough inside light to begin with.

The real problem is that tennis is played with a small, fast-moving white ball which is hard to see against the background of a white bubble. In Bubble No. 1, there wasn't enough contrast for the players even after the intensity of the lighting had been stepped up to an acceptable level.

Mr. Lam solved the contrast problem in this case by telling Mr. Mears to dye his tennis balls red — a solution scorned at first by tennis buffs, including Mr. Mears. It worked out splendidly. So did Mr. Lam's suggestion for maintaining the contrast of dark ball against light background by painting Bubble No. 1's black asphalt court pale blue.

In the new tennis court bubble, the same problem has been solved without abandoning the traditional white ball — or the traditional green of the "grass" court — by lining the bubble's end walls with dark-green plastic up to a height of 12 feet. This provides a dark background for the ball. It also cuts down the natural light intake through the ends of the bubble. On clear days, though, the slight light loss is insignificant; on cloudy

Sunlight diffused through translucent bubble skin lights pool adequately except on dark winter days. Arches traced by bubble's seams give Gothic flavor to interior space



days, artificial lighting is needed in the bubble anyway.

A third solution, suggested by The Architects Collaborative, might be a wide, green gauze netting hung at either end of the bubble. The netting would provide a dark background for the ball and admit light at the same time.

Except at night, the less stringent lighting requirements for the swimming pool bubble could have been met by using what Birdair calls "cathedral windows" in the bubble's side. Tall, slender, and set close together, these windows can be seen in the bubble-covered swimming pools at Atlantic City. Until recently, they were made of transparent Mylar 5/1000 of an inch thick. Mylar, however, has poor tear resistance. When punctured, it will rip like cellophane. For this reason, if cathedral windows are used, they are now made of transparent vinyl film, which is 20/1000 of an inch thick.

Esthetically, the windows are handsome, and certainly they are sturdier than before. But practically, they weaken the bubble, and could be victims of vandals or high winds. Mr. Mears decided against them, even though they might have made natural light sufficient until dusk on all but the darkest days.

Providing enough light to play games or swim by is not the only problem encountered in lighting bubbles, or even the most serious. Yet another problem can stem from the design of the lighting fixtures themselves. Sharp-edged fixtures set on high poles, for example, will

Ledge attachment for swimming pool bubble extends across canopy linking pool with commons building. Double doors at either end of canopy provide access for swimmers and spectators

tear the fabric if a heavy windstorm comes along and the bubble sags against the lights.

In Atlantic City, bubble owners solve this problem with 15-foot-high poles bent in a sweeping inward curve, following the curve of the bubble walls. At the end of these poles are rounded lights shining down on the swimming pools. The theory is that if the bubble were partly deflated, the skin would simply rest on these curved supports. Mr. Mears, however, feels that even curved supports would be risky if a partly deflated bubble were caught in a high wind. He prefers such alternate solutions as demountable poles, poles that telescope into the ground, and lights set in the ground.

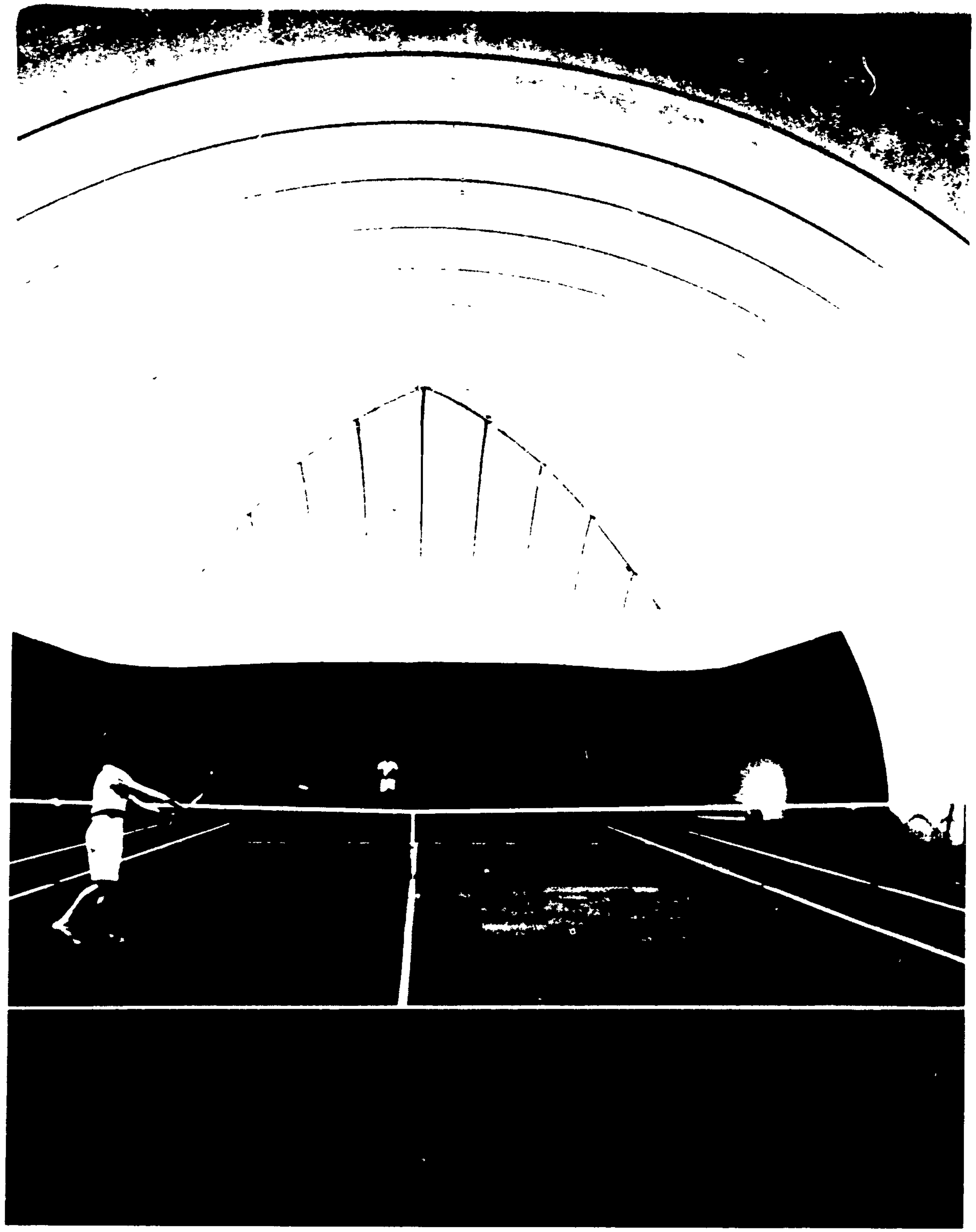
Lights — or other heavy objects — should never be sewn to the bubble's fabric. On the advice of a Birdair installer who had been insufficiently indoctrinated, Forman did just that in the winter of 1962. Then a terrific snowstorm partly deflated and whipped Bubble No. 1. Within moments, the lights were hanging by a few threads, and would have been flung to the floor had not rescuers arrived.

For both Forman School bubbles, William Lam finally planned fluorescent lighting of great intensity, the kind normally used as lighting for billboards.

In the swimming pool bubble, a fluorescent tube, 64 feet long in 8-foot sections, lies inside an aluminum trough that reflects the light. The trough, which can be canted to throw the light in different directions, is set atop the wide concrete canopy that projects from the Commons Building into the pool enclosure. In winter, the trough is tilted upward to bounce light off the bubble's ceiling. In the summer, when the bubble is removed, it is canted downward to shine light directly into the pool. The wattage from this light source is about 2,000, but it seems much brighter because the light is a continuous bar rather than spots of brightness from many fixtures. Also, it is supplemented by underwater fixtures that add to the variety of lighting possible with the tube and trough system, and provide an alternate system for nighttime swimming parties.

The same kind of tube and trough, set on demountable or telescoping poles, was planned for the tennis bubble. William Lam's recommendations called for two 100-foot strips on either side of the court, providing 6,000 watts fluorescent , with the aluminum trough perforated on one side so that light could shine through to illuminate the lower part of the wall.

When the new tennis bubble was put up, however, Mr. Mears simply moved in the fixtures — a sizable investment by then — that finally solved the problem of lighting Bubble No. 1. Along the sides of the bubble, curved collapsible poles, three to a side, are set in holes in the court. The poles are swiveled at their base so that the lights can be lowered to the floor quickly and easily when bad weather threatens, leaving nothing "sticking up" in the bubble.



Quartz lamps atop curved collapsible poles light court for night and dark-day tennis. Floor-mounted lamps light end walls, which are lined with green plastic to contrast with white ball

Six 1,500-watt quartz lamps attached to these 20-foot poles throw direct light on the court. In addition, four similar 500-watt lamps are mounted on the floor, two at each end of the bubble. One lamp in each pair is aimed at the green plastic lining on the bubble's end wall. The second lamp beams light at the ceiling so that players can see lobs more easily.

THE BUBBLE VERSUS THE ELEMENTS

Like badly designed lighting, snow can pose problems for air-supported structures. One night in 1962, a wet, heavy snow fell on Forman Bubble No. 1, clung to the roof, and piled high. Then, in a sudden avalanche, it slid off the roof, burying and suffocating the two blower fans outside the bubble. By dawn, the bubble had sagged halfway to earth.

The problem was caused by placing the unprotected blowers with their intakes low to the ground. It was corrected by building a housing over each fan with air inlets protected and set six feet above ground.

In Bubble No. 2, there is no such problem. Heating and air pressurization equipment is sheltered in the basement of the commons building alongside the bubble. Fresh air is swept in by fans and heated by a boiler; other fans blow the air up into the bubble through hot air registers and a trench around the pool. The used air is drawn back down into the basement, mixed with heated fresh air, and the cycle begins again.

In parts of the country with heavy snowfalls, snow loads on the bubble need not be a worry provided the snow is not allowed to pile too high. Snow can be removed easily in several ways:

By beating the side of the structure, which causes snow to slip down from the dome.

By deflating the bubble 5 to 10 per cent, as the Army does. Ice and frozen snow crack as the taut structure goes limp. Army engineers then blow the bubble back up; the expanding movement thrusts the load off the structure.

Or a man can stand on one side of the bubble and toss a rope to a man on the other side. As they run the rope along the top, it breaks up snow and ice.

Extreme cold does not affect the bubble skin to any important degree. The thin vinyl coating on the nylon may become somewhat brittle during zero weather and below. But neither the Army, which has seen the bubbles perform well in the Arctic, nor Forman, where zero temperatures are common, anticipate any trouble.

DO'S AND DON'TS OF AIR STRUCTURES

To recapitulate, the experience with Bubble No. 1 was a lesson for everyone connected with Bubbles No. 2 and 3. Based on this experience, The Architects Collaborative drew up a 10-point, quick check-list of things to watch out for in air-supported structures. The list follows.

1. Provide positive anchorage.
2. Provide positive drainage.
3. Protect the envelope from sharp objects during erection.
4. Provide protection against sharp protrusions inside the bubble.
5. Control air leakage from envelope. (A taut skin is required to withstand high winds, storms.)
6. Remove snow unless internal pressure is sufficient to compensate for maximum snow load.
7. Protect fan inlets from snow or other obstruction.
8. Periodically check inflation equipment. (Worn or loose fan belts can cause a loss of air pressure.)
9. Provide auxiliary generators to maintain blower operation in case of power failure.
10. Don't attach lights to bubble-skin.

These are the limitations and potential sources of trouble in air-supported structures. But the present advantages and future possibilities they offer cannot be denied. According to *Architectural Forum:*

"It might be said that the air building is the greatest invention since the tent, except that the tent, by comparison, does not seem to have been such a great idea after all. No nomadic visionary could imagine tenting an entire city with a single fabric, yet this is a possibility, albeit still a remote one, with the air structure. Moreover, with an air building (but not with a tent) clear spans of 300 or 400 feet are easily possible."

For now, for school sports, The Forman School feels that the air structure offers positive advantages. Stowell Mears lists these points in its favor:

1. It costs but a fraction of the price of a conventional building.
2. It is inexpensive to heat because it is heated only when it is being used. There is no mass (walls, floors, and such) to heat — only air.
3. It is inexpensive to light because of the skin's reflective qualities, and because sunlight is uniformly diffused without glare.
4. It provides an unobstructed clear span.
5. It is demountable and portable so that outdoor facilities become easily available in the summer.
6. The air structure is easily cleaned and requires little maintenance.
7. Properly engineered with respect to air pressure, fan location, entrance air locks, anchorage, drainage, demountable lights and other interior obstructions, and strength and durability of fabric, air structures are completely dependable.

The principal disadvantage might be the bubble's limited life expectancy. However, new materials are now being promised which will resist the ultraviolet rays of the sun — the main cause of deterioration and aging. "If these materials live up to their advance billing," Mr. Mears predicts, "the air structure will prove to be a major advance in the field of large buildings."

Photography: Page 11 (top) EDWARD HAZEN REED; Page 11 (bottom), Page 19, BUDNEY, courtesy THE FORMAN SCHOOL; all others by GEORGE ZIMBEL
Design: MCARTHUR MCLAIN
Printing: GEORGIAN LITHOGRAPHERS, INC.

Library of Congress Catalog Card #64-21211
First Printing, May 1964
Second Printing, December 1964

Additional copies are available from
Educational Facilities Laboratories
477 Madison Avenue
New York, N. Y. 10022

EFL Publications

Available from Educational Facilities Laboratories, Inc., 477 Madison Avenue, New York 22, New York

THE COST OF A SCHOOLHOUSE
A review of the factors contributing to the cost and effectiveness of schoolhousing, including planning, building, and financing.

DESIGN FOR ETV — PLANNING FOR SCHOOLS WITH TELEVISION
A report on facilities, present and future, needed to accommodate instructional television and other new educational programs. Prepared for EFL *by Dave Chapman, Inc., Industrial Design.*

COLLEGE STUDENTS LIVE HERE
A report on the what, why, and how of college housing; reviews the factors involved in planning, building, and financing student residences.

TO BUILD OR NOT TO BUILD
A study of the utilization of instructional space in small liberal arts colleges, with a do-it-yourself workbook for the individual use of the institutions that wish to survey their own utilization levels.

THE SCHOOL LIBRARY
A report on facilities for independent study, with standards for the size of collections, seating capacity, and the nature of materials to be incorporated.

BRICKS AND MORTARBOARDS
A report on college planning and building; how colleges can provide enough space for the burgeoning enrollments of this decade.

PROFILES OF SIGNIFICANT SCHOOLS *A series of reports which provide information on some of the latest developments in school planning and design.*

Belaire Elementary School, San Angelo, Texas
Heathcote Elementary School, Scarsdale, New York
Montrose Elementary School, Laredo, Texas
Two Middle Schools, Saginaw Township, Michigan
Newton South High School, Newton, Massachusetts
Holland High School, Holland, Michigan

Schools for Team Teaching — ten representative examples
High Schools 1962 — educational change and architectural consequence

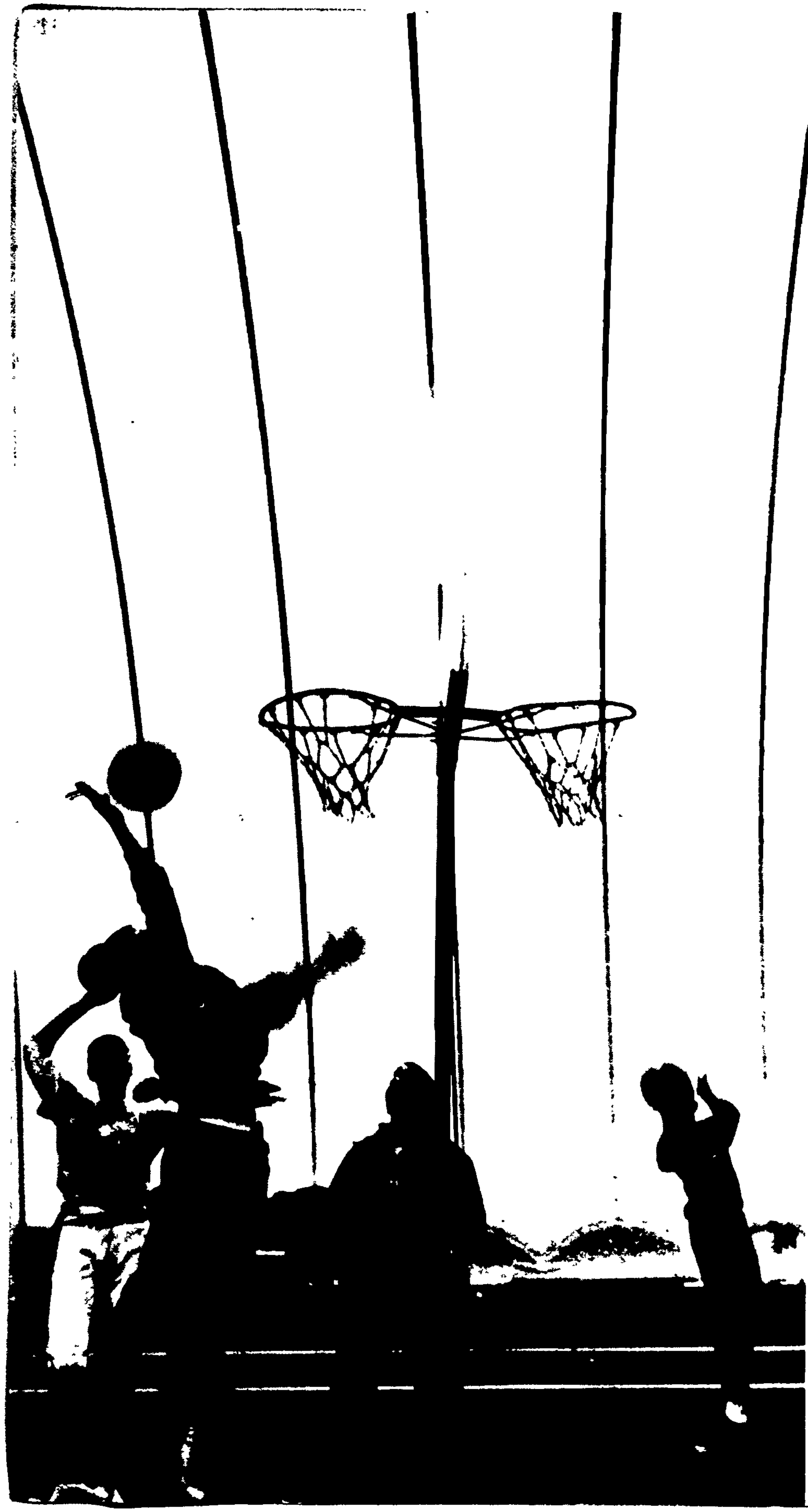
CASE STUDIES OF EDUCATIONAL FACILITIES
A series of reports which provide information on specific solutions to problems in school planning, design, and construction.

1. CONVENTIONAL GYMNASIUM VS. GEODESIC FIELD HOUSE *A comparison of cost, space, and advantages based on a case study of West Bethesda High School, Montgomery County, Maryland.*
2. SPACE AND DOLLARS: AN URBAN UNIVERSITY EXPANDS *A report on the economical physical expansion of urban universities based on a case study of Drexel Institute of Technology.*
3. LABORATORIES AND CLASSROOMS FOR HIGH SCHOOL PHYSICS *Chapter reprinted from* Modern Physics Buildings: Design and Function.
4. A DIVISIBLE AUDITORIUM/BOULDER CITY, NEVADA *Case study of an auditorium that can be converted to instructional spaces by the use of soundproof, operable walls.*
5. NEW CAMPUSES FOR OLD: A CASE STUDY OF FOUR COLLEGES THAT MOVED *What the decision to move means from an economic, academic, social, and physical point of view.*
6. A COLLEGE HEALTH CENTER *Case study of a model center for small private colleges; architectural design by Caudill, Rowlett & Scott.*
7. NEW BUILDINGS ON CAMPUS: SIX DESIGNS FOR A COLLEGE COMMUNICATIONS CENTER *A portfolio of prototype schemes entered in an architectural competition sponsored by Rensselaer Polytechnic Institute.*
8. THE SCHOOLS AND URBAN RENEWAL: *A case study from New Haven.*

TECHNICAL REPORTS

1. ACOUSTICAL ENVIRONMENT OF SCHOOL BUILDINGS

COLLEGE NEWSLETTER
A periodical on design questions for colleges and universities.



CASE STUDIES 9 OF EDUCATIONAL FACILITIES