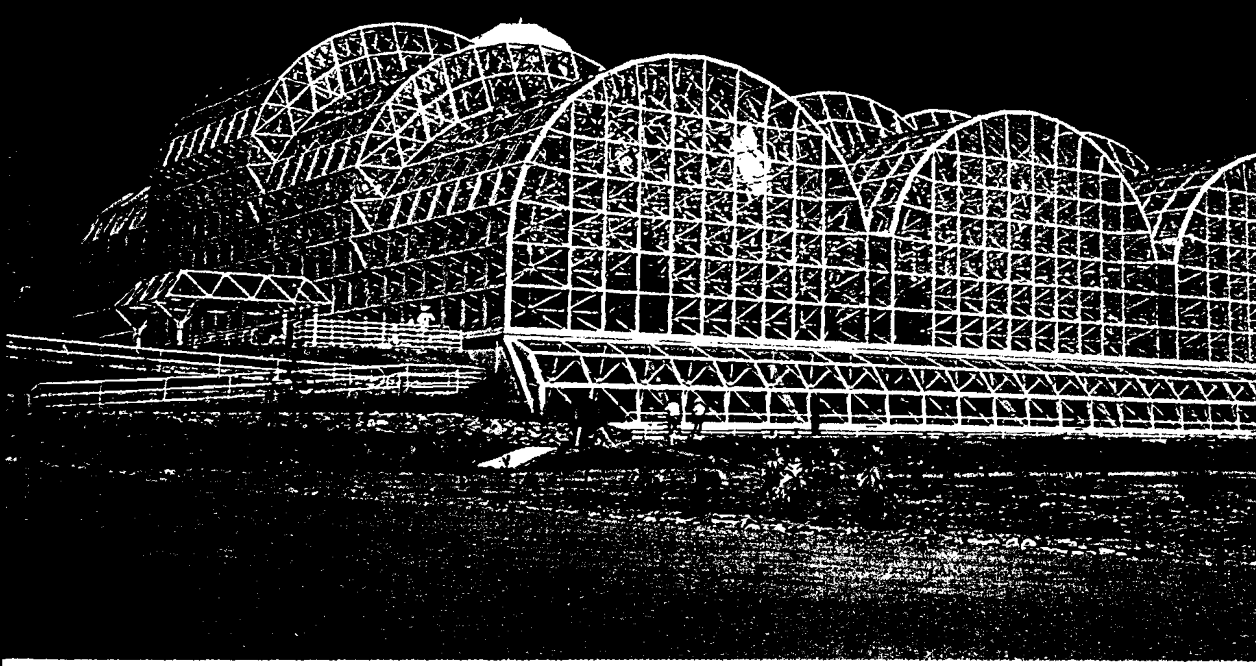
BIOSPHERE 2

RESEARCH PAST & PRESENT



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Short communication

The Biosphere 2 canopy access system

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Abstract

Access to the rainforest canopy of Biosphere 2 presented a unique challenge to design and build a fall arrestance system that would meet the needs of the ecological research community and ensure a high degree of safety for users. The system was based on technology typically used in canopy research in field settings, but differed due to the presence of the steel spaceframe that enclosed the mesocosms of Biosphere 2. This paper reports the design of a fall arrestance system that meets federal regulations for health and safety and an example of gas exchange data collected in the canopy of the Biosphere 2 rainforest. The preliminary results from leaf gas exchange measurements indicated distinct differences between understory and canopy plants, emphasizing the importance of access to the canopy for experimental research. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

Much of the work in natural rainforest canopies involves estimating the load carrying capacity of trees based on visual observation, judgement and professional experience. A variety of systems have been designed, constructed and tested and utilized successfully in forests around the world at heights of up to 50 m (Lowman and Bouricius, 1995). In many natural forest situations, canopy access structures utilize several tall canopy tree trunks for structural support. In the case of Biosphere 2 the relatively young trees in the rain forest mesocosm precluded this approach. Access to the canopy of the rainforest biome (Leigh et al., 1999) required a simple design with minimal light reduction and impact on the plants, maximum accessibility to the canopy for research activities and safety compliance under applicable US laws.

Historically, access to the rainforest canopy at Biosphere 2 was limited to experienced climbers in the operations and maintenance departments and to researchers with extensive experience in canopy climbing. The Biosphere 2 spaceframe served as an anchorage point above specific plants for observation or pruning or to maintain elevated mechanical and electrical systems, windows, etc. However, while professional climbers and arborists often have special training, years of experience and are generally in good physical condition (Moffet and Lowman, 1995), opening the canopy up to a variety of researchers required a system accommodating a wide range of skill sets and ease of use of equipment once aloft. We describe here the design and use of a fall arrestance system for the Biosphere 2 rainforest canopy which allowed direct measurements of physiological processes at the top of the canopy.

2. Design, applicable standards, materials and use of the fall arrestance system

The principal design features of the fall arrestance system were constrained by the strength of the supporting spaceframe, potential areas of canopy access within the rainforest biome, the relatively young age of the trees under study, ease of maneuvering while aloft, and compliance with Occupational Health and Safety Administration (OSHA) Standards for Fall Protection. The final design called for access along two axes within the canopy using cables attached at opposite points (Fig. 1a). A double cable system was used to allow a transect for the researcher to follow along the cable and offer stability while stationary in a safety seat but active with instrumentation. This system would allow researchers both horizontal and vertical access to major species within the rainforest biome of Biosphere 2 (Fig. 2a). A structural engineer was employed to design the system to model the anticipated lateral load of up to 5000 lb on the frame if a climber fell and to design an attachment system to connect the cable (Permacable™) to the spaceframe. Databases established during the design of the spaceframe employing finite element analysis (FEA) were used to model the capacity of the spaceframe design elements to safely maintain the 5000 lb load required for the OSHA Fall Protection

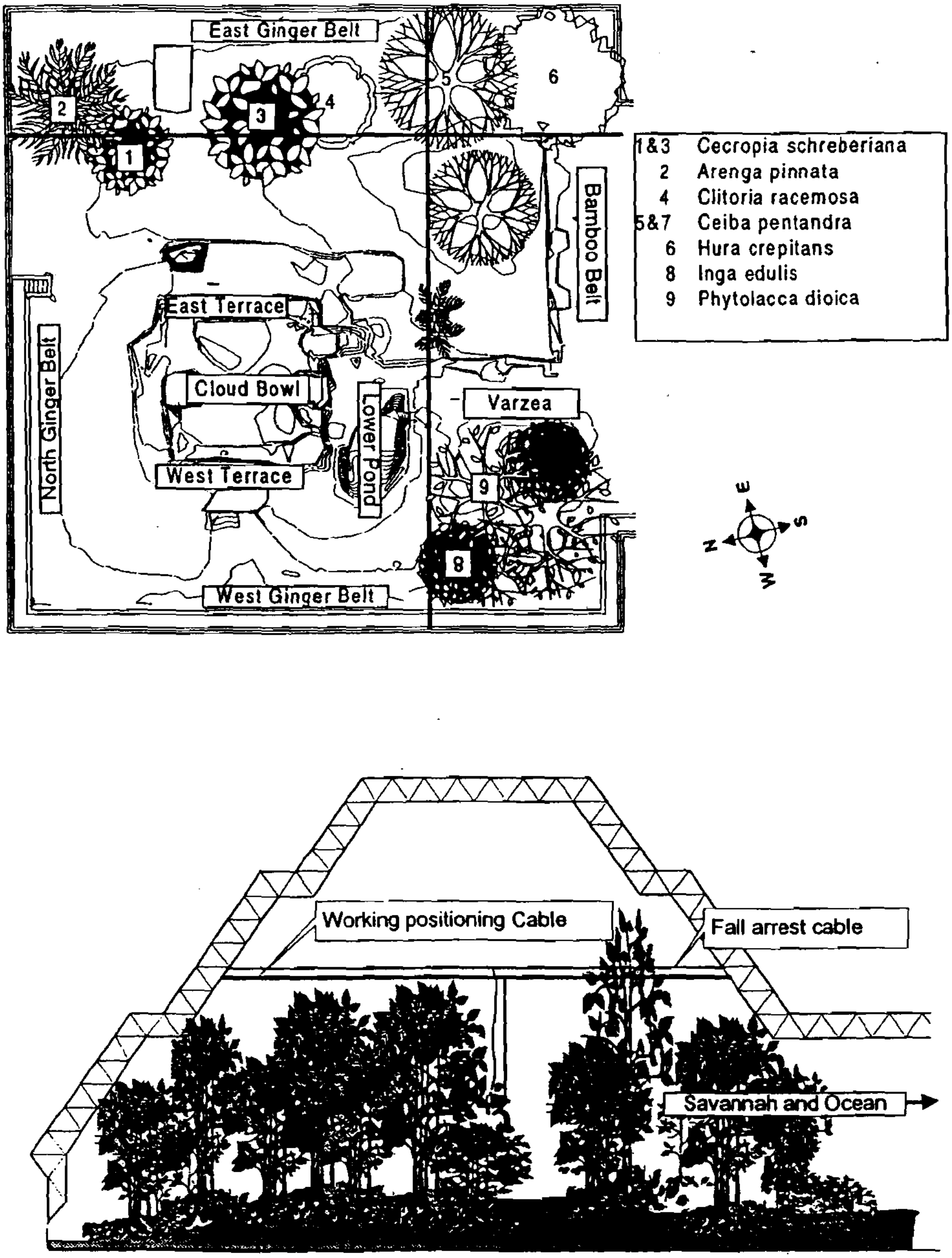

Fig. 1. Rainforest mesocosm of Biosphere 2. (a) Topview (not to scale) of the Biosphere 2 rainforest showing species locations of canopy trees (1, 3) *Cecropia schreberiana*; (2) *Arenga pinnata*; (4) *Clitoria racemosa*; (5, 7) *Cebia pentandra*; (6) *Hura crepitans*; (8) *Inga edulis*; (9) *Phytolaca dioica*; (10) *Ptereoarpus indicus*) and alignment of the double cable fall arrestance system used to access the canopy trees. (b) Cross section view (not to scale) of the rainforest mesocosm, with climber in the canopy, showing the vertical placement of the cable system and attachment points within the spaceframe.

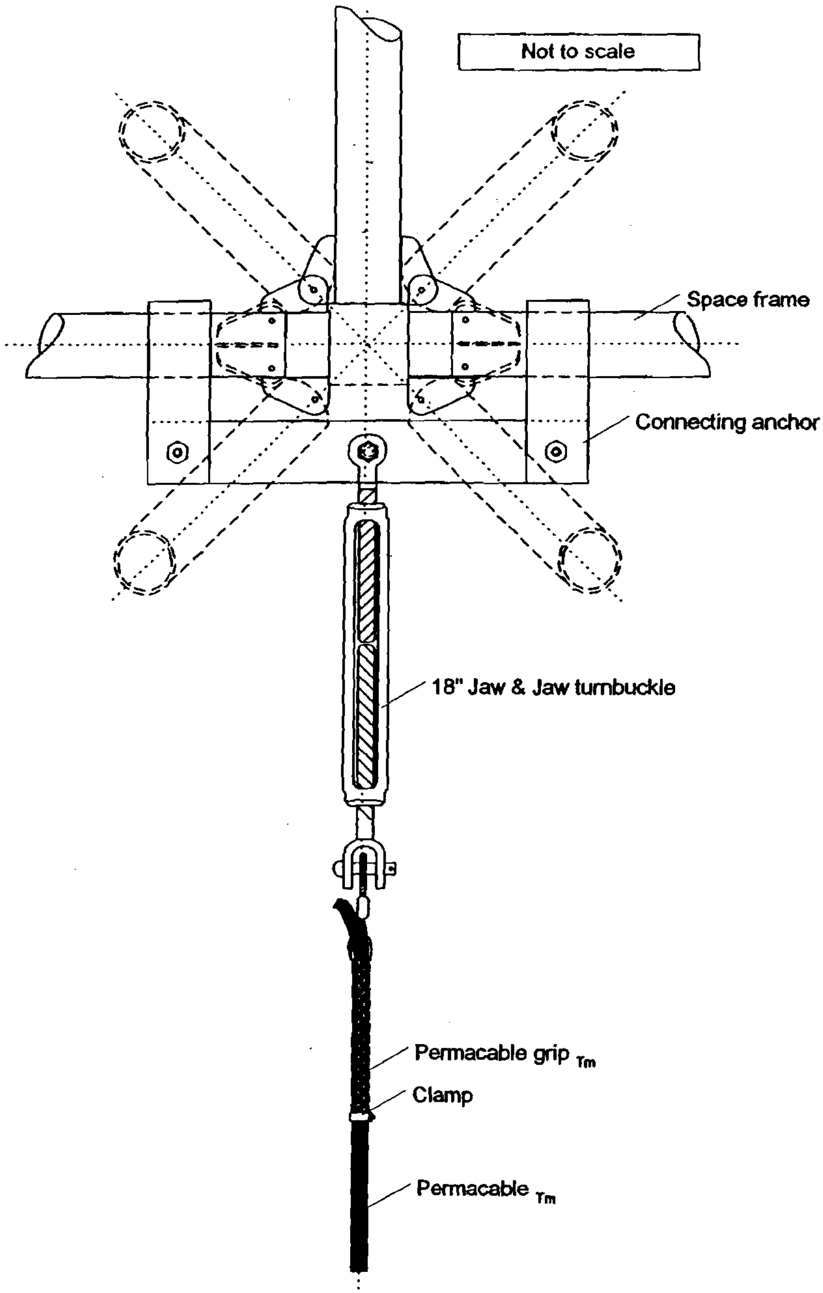

Fig. 2. CAD drawing of the spaceframe bracket and cable attachment hardware. The assembly design allowed for placement of custom made brackets that were positioned on both sides of the space frame node centers. The brackets were interconnected with flat connector bars drilled in their centers to accept the shackle end of turnbuckles. The Permacable™ then attached to the turnbuckle, which provided final adjustment for correct tensioning across the span (approximately 2 ft static/4–5 ft dynamic at mid point). This design did not rely on welding, taking advantage of the inherent strength of materials in both the bracket assembly and the node tubes themselves.

Standard. The model results confirmed the feasibility of the additional load at the interconnecting nodes of the spaceframe.

Canopy access has historically not been designed in compliance with OSHA standards (Lowman, personal communication). In this sense, the Biosphere 2 design represents a unique contribution to the field of forest research. The US Department of Labor's OSHA has listed falls as a leading cause of traumatic occupational death (Ellis, 1993). Designing, installing, testing, using and maintaining the Biosphere 2 canopy access/fall protection system had to comply with all applicable US standards. The standards are generally divided between occupational regulations (OSHA) and equipment requirements (ANSI, 1991–1992). As an employer, Biosphere 2 was covered by the General Industry Standards of the Arizona Department of Occupational Safety and Health (ADOSH). This state agency had adopted all federal labor standards for fall protection including the Code of Federal Regulations (CFR) 29 1910.66, Appendix C (CFR, 1910). This standard required that the Fall Protection Plan include proper orientation and training, comprehensive inspection, maintenance and audit of the system. The fall arrestance system consisted of four basic parts: (1) two horizontal cables attached to the spaceframe with engineered anchorage points for the purpose of work positioning and fall arrestance, (2) a patented mechanical assist device for ascending into and descending out of the canopy (3) a bosun's chair with instrument harness and (4) a full body harness with shock absorbing lanyard.

Selecting the proper equipment for a personal fall arrestance system was critical to ensuring safety for all users. As such, the American National Standards Institute (ANSI) presents a set of guidelines for major fall arrest equipment and fall arrest systems. All key components for the Biosphere 2 canopy access/fall protection system met these standards, as verified in manufacturers literature as well as component labeling. Furthermore, these components were tested, where applicable, under dynamic conditions. The OSHA Fall Protection Standard required anchorage's for the primary fall arrestance cable to support a dynamic load of at least 5000 lb of force. The Permacable™ Horizontal Lifeline System was chosen for this purpose. This cable was manufactured of 5/8 inch low stretch neoprene coated synthetic parallel fiber fabricated specifically to span the 100 ft required distance in the rainforest (Fig. 1a, b). The primary components are illustrated in Fig. 2. All attachment material was machined out of AISI 316 stainless with a minimum yield strength of 30 000 psi. Teflon coatings were used at the node/attachment bracket interface to protect the spaceframe from damage as the assembly rotated due to changes in loading from the Permacable™.

To utilize the assembled system, researchers needed a device for ascent and descent. A patented device, called a Rollgliss™, was used because of several design advantages. The device used a block and tackle pulley system allowing for a 3:1 mechanical advantage when lifting. In addition, the device provided a 95% braking action when the lifting force stopped; there was no requirement for the climber to apply a counterforce to equal the load, should he/she want to stop the ascent or should a climber accidentally release the rope. A Ropelok™ device on the line limited free fall to less than 2 ft, further reducing the chance of injury should the work positioning cable fail. Maintenance of the system consisted primarily of periodic inspection of all components, per manufacturers specifications, which included adjustment of the mid-span tension in the Permacable™, factory re-certification of the Rollgliss system on a biannual basis including the rope and inspection of all personal fall arrestance gear including lanyards, full body harnesses, carabiners, etc.

Before the system could be used, all individuals required to use it completed a comprehensive training program that included background on the hazards of canopy work, the applicable fall protection standards, demonstration and explanation of the equipment and supervised practice on the system. Canopy access was always performed by a minimum of two individuals; the actual climber and a ground support person. Fig. 3 shows a climber aloft collecting data with a LI-COR 6464 system.

3. Data collection in the Biosphere 2 rainforest canopy

We conducted a series of leaf gas exchange measurements in the canopy using a LI-6400 portable photosynthesis system. The fall arrestance system allowed mea-

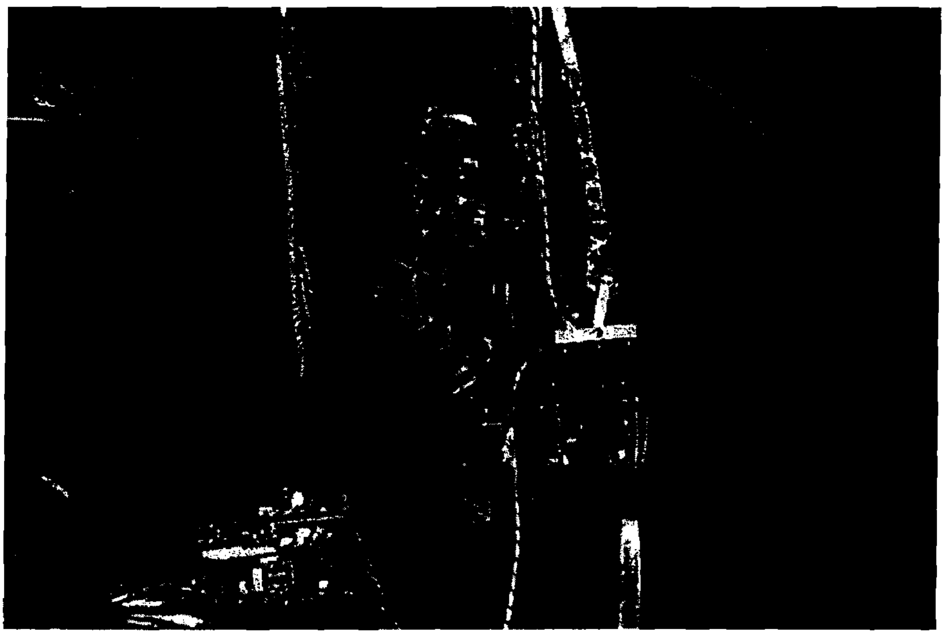

Fig. 3. A climber conducting measurements in the canopy with a portable LICOR photosynthesis instrument. The climber sat in a Bosun's chair, with the LICOR instrument secured overhead and in front of the user. The Rollglis™ system was attached to a separate stainless steel work positioning cable. A full body harness with shock absorbing lanyard was attached by a 3/8 in. kernmantle rope (5000 psi breaking strength) to the Permacable™ for fall arrestance.

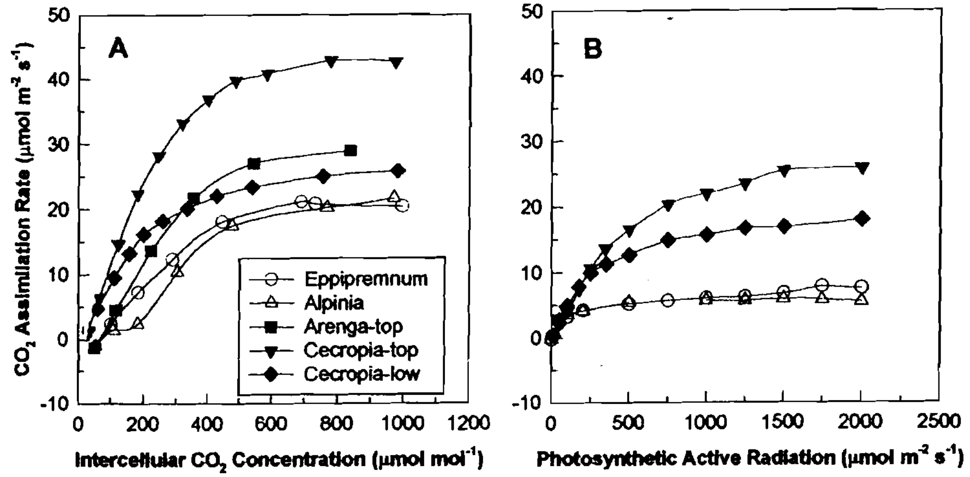

Fig. 4. Leaf photosynthesis rates of understory (open symbols) and canopy (filled symbols) plants under different CO_2 concentration (A) and light intensity (B) in the tropical rainforest of Biosphere 2. The environmental conditions were: (A) 30° air temperature, light intensity of 2000 μmol m^{-2} s^{-1} for all CO_2 concentrations and 80% relative humidity, (B) 30°C air temperature, 350 μmol CO_2 concentration and 80% relative humidity. For *Cecropia*, leaves at the top of the canopy (12 m above the ground) and at the bottom of the canopy (8 m above the ground) were measured.

surements of short term responses of leaf photosynthesis under differing concentrations of atmospheric CO_2 and light conditions within the rainforest mesocosm. Two canopy species (*Cecropia schreberiana* and *Arenga* sp.) were compared with two common understory plants (*Eppipremnum pinnatum* and *Alpinia zerumbet*). The results are shown in Fig. 4 and indicate that canopy species in the tropical rainforest of Biosphere 2 had distinctly different leaf photosynthetic rates compared with leaves from understory plants as a function of atmospheric CO_2 concentration (Fig. 4A, under constant light intensity of 2000 μmol m^{-2} s^{-1}) or light intensity (Fig. 4B, under CO_2 concentrations of about 350 μmol mol^{-1}). Even for the same species, such as for *Cecropia*, leaves at the top of the canopy and at the understory, showed different photosynthetic responses. Since these characteristics of leaf physiology are critical in assessing ecosystem function, it is necessary to conduct direct leaf level canopy measurements. The canopy access system described here is important for experimental studies using the rainforest of Biosphere 2.

4. Conclusions

Canopy access at Biosphere 2 was implemented by considering interrelated requirements of knowledge of the original spaceframe engineering, a clear understanding of sample collection needs defined by the scientific community and strict adherence to the applicable health and safety standards and equipment manufacturer's specifications. Use of top quality equipment and supplies and development of a competency-based training program ensured the safety of system users. This system provided the scientific community with access to a rainforest canopy that will be integral in experimental studies of the Biosphere 2 rainforest.

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