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# TECHNOLOGICAL PRINCIPLES FOR CREATING A SUIT THAT ENSURES HIGH RELIABILITY AND SAFETY IN AQUATIC ENVIRONMENTS

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**Abstract:** This article analyzes the technological foundations for creating a specialized suit that ensures high reliability and safety in aquatic environments. The study examines hydrodynamic conditions, the water resistance of materials, heat transfer, and compliance with ergonomic and biomechanical requirements. The rationale for applying functional zoning, a multilayer structure, and innovative sewing technologies in the suit's construction is substantiated. Based on the research findings, scientific and practical recommendations have been developed for designing a high-performance and safe suit.

**Keywords:** aquatic environment, functional suit, reliability, safety, ergonomics, hydrodynamic characteristics, water-resistant materials, multilayer structure, seam/sewing technology, rescue suit.

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**Introduction.** The aquatic environment is among the most complex and hazardous settings for human activity. Apparel used in water sports, rescue operations, and specialized professional tasks must provide not only comfort but also a high level of reliability and safety. Movements performed under water or on the water's surface may constrain the body's physiological capacities and adversely affect heat exchange and respiration. Therefore, the design of specialized suits for such conditions calls for particular emphasis on advanced materials, innovative technologies, and ergonomic approaches. The hydrodynamic form, water resistance, thermoregulatory characteristics, and mechanical strength of the suit directly determine user safety. In extreme conditions—such as cold water, elevated pressure, waves, and currents—the level of protection afforded by the suit plays a critical role in preserving human life. At the same time, for rescue personnel, aquatic sports athletes, and industrial specialists operating in water environments, compliance with ergonomic requirements is equally essential.

Research on the development of aquatic sports apparel primarily addresses fundamental issues such as thermal insulation, water impermeability, durability, and ergonomic compatibility. For example, Bardy, Mollendorf, and Pendergast compared the thermal insulation performance of neoprene-based wetsuits with a hybrid layer incorporating aerogel [1]. Their laboratory experiments showed increased thermal resistance when aerogel was added; however, field tests did not confirm the benefit because flexibility decreased. This indicates that for athletes, not only thermal insulation but also ergonomics and comfort are decisive factors. Similarly, Moran and colleagues succeeded in reducing the thermal conductivity of closed-cell neoprene to as low as  $0.031 W/m \cdot K$  by infusing the cells with inert gases, demonstrating that high levels of thermal protection can be achieved without increasing material thickness [2]. This approach is highly relevant for slalom paddlers aiming to perform effectively in severe cold conditions.

Korinteli, in his PhD dissertation, developed new types of neoprene packages for water sports. He proposed hot welding (welded seams), specialized elastomeric coatings, and novel seam constructions [3]. Korinteli's results indicate that properly selected seam types and coatings significantly enhance the suit's water impermeability and thermal efficiency [4,5].

Lee, Kim, and Choi investigated ergonomic compatibility in wetsuits by using neoprene panels of varying thickness. They found that placing thicker material over the body's core regions and thinner, more extensible material in high-mobility zones—such as the axillae and the popliteal area behind the knee—sharply improved athletes' freedom of movement [6].

Another important line of contemporary research on aquatic sports apparel concerns innovations in inner linings. Denny and Nichols compared graphene-infused fabrics with conventional polyester fleece and found that graphene coatings enable the body to retain heat more effectively [6]. This property is particularly critical for keeping an athlete's core temperature stable during short intervals between high-intensity starts.

In addition, Wei, Ye, and Zheng conducted a simulation-based study on the application of phase change materials (PCM) in wetsuits. Their results showed that PCM capsules can attenuate thermal fluctuations in the athlete's body [7]. Wang and colleagues further elaborated on this approach, emphasizing that PCM technology is a promising avenue for thermal management in sports apparel [8].

Tomczak and Krol analyzed the classification and practical solutions of advanced technological materials for water-sports apparel, highlighting in particular the effectiveness of hybrid composite textiles [9]. For example, Sharkskin's three-layer Chillproof material (fleece + membrane + water-repellent outer layer) not only retains heat but also dries quickly and provides high comfort for athletes.

Seam and joining technologies likewise play a pivotal role on the innovation front. Oh and colleagues examined the effectiveness of glued-and-blindstitched (GBS) seams and found that they significantly increase the level of water impermeability [10]. Shei Chung Hsin, in turn, patented multilayer, abrasion-resistant neoprene constructions, thereby enhancing durability for athletes [11].

Literature analysis indicates that innovations in aquatic sports apparel over the past decade have focused on three principal directions:

1. Material innovations — aerogel, noble-gas-filled neoprene, graphene, and PCM;
2. Seam and fastener technologies — GBS (glued-and-blindstitched), liquid seam seal, and hot welding;
3. Ergonomics and hybrid design — zonal thickness distribution, three-layer technical fabrics, and fast-drying hybrid packages.

Taken together, these advances underscore the need to integrate heat retention, water impermeability, durability, and comfort when developing specialized apparel for slalom paddlers.

Developing high-reliability protective apparel for aquatic athletes—particularly slalom paddlers—requires a multidisciplinary approach that integrates materials science, ergonomics, and sports engineering. The technological foundations of such garment design are directed toward ensuring safety, maintaining thermal balance, and optimizing mobility under extreme aquatic conditions. Because slalom paddlers operate in turbulent flows at varying temperatures, the suit must withstand continuous exposure to cold, water impact, and mechanical abrasion while simultaneously providing comfort and enabling high performance.

**Thermal Protection and Insulation.** One of the primary technological requirements for slalom suits is thermal insulation. Traditional neoprene wetsuits are based on a closed-cell foam structure, in which a thin layer of water forms between the skin and the suit; this layer warms under body heat and provides insulation [1]. However, there are inherent trade-offs in balancing thickness, elasticity, and thermal performance. Studies show that increasing neoprene thickness improves heat retention but reduces elasticity and restricts movement—an especially serious issue for slalom paddlers, who require a high degree of freedom in the shoulder and arm complex.

Recent innovations have introduced neoprene composites containing aerogel, which markedly increase thermal resistance without adding excessive bulk. Nevertheless, while laboratory results are promising, field trials have revealed issues with flexibility and seam integrity, underscoring the need for hybrid solutions.

**Strength and Mechanical Resistance.** In addition to thermal insulation, resistance to abrasion and impact is critical to the safety and service life of slalom suits. During competition, athletes may collide with rocks, the interior of the boat, and gate poles. Research on abrasion-resistant laminates shows that laminating neoprene with nylon or Kevlar markedly increases resistance to wear and tearing, while exerting only a modest adverse effect on elasticity. Patented multilayer wetsuit constructions use outer protective layers to absorb and dissipate mechanical stresses, thereby preserving the integrity of the inner insulating layers. This principle is particularly salient for slalom suits, where reinforced knee and elbow panels are essential for long-term performance.

**Ergonomics and Safety Factors.** In the technological approach to suit design, ergonomics occupies a primary position. A close-fitting garment reduces water ingress, which would otherwise degrade insulation efficiency. Patterns developed on the basis of 3D body scanning and CAD software account for pre-flexed joint positions and anatomical alignment, markedly improving freedom of movement.

From a safety standpoint, integration with mandatory protective equipment—helmet and buoyancy aid in accordance with International Canoe Federation regulations—must also be considered at the design stage. The suit must not interfere with the operation of the life jacket or restrict rapid doffing in an emergency.

**Hybrid Material Systems.** Recent studies emphasize the principle of hybridizing material systems. For example, Sharkskin and Lavacore have developed multilayer laminates that combine thermal fleece, a breathable membrane, and durable outer shells. These constructions have been shown to outperform conventional neoprene in terms of

thermal comfort and drying speed [12]. Such hybrid packages are particularly important for slalom paddlers, since competitions are often held under variable conditions.

Three foundational pillars of high-reliability suits. The technological basis of high-reliability aquatic-sports apparel rests on three interrelated pillars:

1. Advanced thermal insulation (neoprene, aerogel composites, graphene coatings);
2. Strength and abrasion resistance (laminated textiles, reinforced zones, improved seams);
3. Ergonomic design for safety and mobility (anatomical patterning, hybrid breathable–insulative systems).

Overall, these principles guide ongoing research toward the development of aeroprene-based material packages and design methodologies aimed at ensuring the safety and performance of slalom paddlers in extreme aquatic environments.

**Classification of Suits for Aquatic Sports and Their Modern Design.** Modern aquatic-sport suits—especially those used in canoe slalom—are broadly divided into wetsuits, drysuits, and hybrid/composite ensembles. Each type is tailored to specific environmental and performance requirements. In competitive slalom, the suit must provide not only thermal protection and hydrodynamic efficiency but also support for intense physical actions such as paddling, rolling, and rapid changes of direction.

**Wetsuits.** Wetsuits are the most widely used category in water sports. They are made from closed-cell neoprene foam and retain a thin layer of water between the skin and the suit; warmed by body heat, this layer serves as insulation. For paddling, specialized silhouettes—such as the sleeveless “Farmer John”—are preferred, as they keep the torso and legs warm while allowing free shoulder movement. Wetsuits are typically classified by thickness (2–7 mm) and coverage (shorty, full suit, long john). For slalom, thinner, more flexible neoprene is generally selected to reduce overheating during periods of high-intensity exertion. Studies further indicate that using thinner neoprene around joints improves ergonomic performance [6].

**Drysuits.** Drysuits constitute another major category designed to keep the athlete completely dry. They are made from multilayer laminated fabrics and incorporate watertight latex or neoprene gaskets at the wrists, neck, and ankles. Unlike wetsuits, drysuits do not provide thermal insulation on their own; athletes wear additional insulating layers underneath.

In very cold conditions, drysuits offer unrivaled protection, though if poorly designed they can restrict movement. Slalom paddlers often opt for lightweight, breathable drytops (a dry shell for the upper body only) paired with neoprene trousers to balance protection and mobility.

**Hybrid and Modular Systems.** Recent innovations place particular emphasis on hybrid systems, in which neoprene-based insulation is combined with breathable, windproof outer shells. For example, Sharkskin’s three-layer Chillproof laminate—comprising a thermal fleece inner layer, a breathable membrane, and a water-repellent, durable outer shell—provides thermal performance comparable to 2–3 mm neoprene

while enhancing comfort in mixed air/water conditions [12]. These hybrid ensembles are typically classified as technical-fabric suits and offer adaptability for environments featuring cold water and warm ambient air.

Modularity is also a distinct classification approach. In canoe slalom, two-piece configurations (e.g., neoprene pants plus a drytop) are common, enabling athletes to adjust to conditions in real time. Ergonomic studies indicate that multilayer dressing is the most flexible strategy for fine-tuning thermal protection.

**Competition-Specific Design Features.** Modern suits intended for slalom athletes incorporate the following characteristics:

- Abrasion-resistant reinforcements (Kevlar or polyurethane overlays at the knees, elbows, and seat);
- Hydrodynamic shaping to reduce drag in water;
- High-visibility color schemes to enhance conspicuity and safety;
- Integration with protective equipment to ensure compatibility with buoyancy aids and helmets;
- Quick-release zippers and ergonomic seam placements to ease donning/doffing and reduce chafing.

The classification of suits for slalom athletes reflects a technological evolution:

Wetsuits — neoprene-based, strong thermal insulation and flexibility, but with a potential risk of overheating.

Drysuits — a fully waterproof shell requiring insulating underlayers; the best protection in cold conditions.

Hybrid/technical suits — breathable, multilayer laminates that deliver high adaptability.

Current design trends emphasize layering, modularity, and hybridization—all aimed at ensuring thermal safety, abrasion resistance, and ergonomic freedom for slalom paddlers imparting Water Impermeability to Modern Suit Materials and Structuring Their Construction.

One of the core attributes of high-performance suits for slalom paddlers is water impermeability. Unlike ordinary sportswear, these garments must withstand continuous immersion, splashing, and high-pressure water impacts while maintaining flexibility and thermal insulation. Over the past decade, significant advances in textile engineering, lamination, and coating technologies have been achieved, resulting in substantial improvements in the water resistance and water-repellent performance of neoprene and hybrid suits.

**Neoprene and Laminated Constructions.** Traditional neoprene, owing to its closed-cell foam structure, is inherently water-resistant. However, with prolonged use certain weaknesses emerge: water ingress through seams and abrasion of the outer surface reduce protective performance. For this reason, manufacturers face-laminate neoprene with fabrics such as nylon, polyester, or Lycra (spandex), which improves durability and water-repellent behavior. Studies show that double-lined neoprene (fabric bonded to both sides) has greater longevity and absorbs less water than single-lined

variants. In addition, stretch laminates enhance comfort while maintaining water impermeability.

**Seam-Sealing Technologies.** In wetsuits, seams are the most vulnerable points. The conventional flatlock stitch creates needle perforations that allow leakage, making it unsuitable for cold environments. Contemporary advanced methods include:

- Blindstitching with adhesive (GBS) – the needle does not fully penetrate the neoprene, thereby reducing water ingress;
- Liquid rubber seam coating – seam lines are overlaid with an elastic, waterproof film;
- Welded/taped seams – heat-bonding technology eliminates needle holes, producing an almost watertight seam.

These technologies increase the long-term functional robustness of slalom suits. In particular, the continuous hydrostatic and dynamic pressures encountered in turbulent rivers severely test garment integrity, and optimized seam engineering helps prevent failure.

**Hydrophobic and Nano-Coatings.** Recent research has focused on surface treatments to enhance water impermeability. Hydrophobic nano-coatings applied to neoprene or polyester laminates sharply reduce surface wetting and spreading, thereby accelerating drying and mitigating evaporative cooling [14]. Laboratory trials have shown that fluorocarbon-free hydrophobic finishes retain their durable water-repellent (DWR) performance even after repeated laundering, meeting the requirements for environmentally safe, non-toxic sportswear. Graphene-based coatings are also attracting attention for simultaneously improving water repellency and in-plane thermal conductivity.

**Structural Innovations.** Engineering improvements to neoprene foams are likewise underway. For example, “super-stretch” limestone neoprene with a high gas-cell density increases flexibility while maintaining water impermeability. Experimental foams infused with aerogel have also been tested; they improve both water resistance and thermal insulation, although practical integration challenges remain (Bardy et al., 2006). Another advance is multilayer composites comprising an abrasion-resistant outer shell, a middle neoprene layer, and an inner hydrophobic fleece. This combination jointly delivers water impermeability, durability, and comfort.

**Application to Slalom Suits.** For slalom paddlers, water-impermeability technologies must also account for ergonomics. Overly stiff laminates or coatings can restrict movement. Consequently, modern slalom suits employ a targeted reinforcement strategy: hydrophobic laminates are placed in zones with high water exposure—such as the chest, arms, and thighs—while stretch panels are preserved in the axillary region and behind the knees. This reflects the principle of functional apparel design—materials and coatings are applied only where necessary, balancing comfort with performance.

Contemporary water-impermeability technologies for paddlers include:

- Laminating neoprene with durable technical fabrics;

Advanced seam-sealing (adhesive bonding, liquid seam overcoats, thermal welding/taping);

Hydrophobic and nano-coatings to boost drying speed and water-repellent efficiency;

Multilayer composites that reconcile stretch, durability, and insulation.

These solutions enable athletes to maintain water impermeability and thermal efficiency while moving freely under continuous splashing and immersion.

**Analysis of Technological Joins and Fasteners in the Design of Suits for Water Sports.** In water-sports garments—especially suits intended for canoe slalom—the construction of seams, joining interfaces, and fastening elements is decisive for achieving water impermeability and ergonomic mobility. Even the most advanced neoprene or hybrid material packages will lose effectiveness if seams leak or if fastening systems fail under extreme conditions. Over the past decade, seam engineering, zipper innovations, and fastening architectures have received heightened attention to improve reliability, comfort, and safety.

**Seams and Joining Technologies.** Although the flatlock stitch is widely used in warm-water suits, it fully pierces the material and thus creates leakage paths at the seams; for this reason it is unsuitable for slalom suits intended for cold conditions. High-quality modern suits employ glued-and-blindstitched seams (GBS), in which the needle does not penetrate the neoprene completely, thereby reducing water ingress. Studies indicate that GBS seams preserve elasticity and thermal insulation better than flatlock seams. In high-reliability suits, additional reinforcement methods are also applied: seam taping (a specialized tape bonded to the inside or outside of the seam) and liquid-rubber seam sealing, both of which render the seam line fully waterproof. The most advanced patents describe thermally welded seams. In this technique, an adhesive film and heat are used to bond panels, eliminating needle holes entirely. Such welded seams are especially advantageous in competitive paddling because they reduce friction and create a smooth surface, thereby improving hydrodynamic efficiency.

**Zippers and Entry Systems.** Fastening elements—particularly zippers—are often the weakest points for water impermeability. Conventional coil zippers allow leakage; therefore, modern slalom suits use waterproof zippers (polyurethane-coated types or TIZIP designs) that compress tightly when closed to prevent ingress. In drysuits, diagonally placed front-entry zippers have become standard, enabling self-donning and reducing strain at the waist and shoulders. However, their placement must be ergonomically optimized, since poor positioning can interfere with paddling motions. Innovations include protective zipper garages at the ends and integration with low-profile seams, which reduce water entry and enhance comfort. Some suits eliminate zippers altogether, using stretch panels at the chest or back for entry; this approach reduces potential leakage points. Popularized in surfing, such systems are now being adopted in high-mobility slalom garments.

**Additional Fastening Elements.** Beyond zippers, slalom suits use Velcro®, snaps, and elastic closures at the wrists, neck, and ankles to achieve watertight seals. Typically,

latex or high-stretch neoprene gaskets are employed. There is a known trade-off between comfort and waterproofing: latex seals block water exceptionally well but may cause discomfort; neoprene seals are more comfortable yet slightly less watertight. Recently developed silicone-coated gaskets improve elasticity and skin adhesion, thereby enhancing comfort.

Ergonomic placement of fastening elements is also crucial. Athletes report reduced fatigue when closures are positioned away from high-pressure zones (e.g., beneath PFD straps) or areas prone to paddle contact. Consequently, functional-apparel design principles call for optimizing the location of these components.

**Integration and Durability.** In slalom suits, the integration of seams and fastening components with the overall material package determines long-term reliability. Poorly bonded seams or quickly wearing zippers are common issues in older designs. Research on protective garments emphasizes multi-factor testing: cyclic flexing, immersion resistance, and abrasion tests of fastening components. Manufacturers increasingly employ stretch-capable, high-durability seam tapes and coated zippers qualified for 10,000+ cycles, aligning with international durability standards (ISO, 2017).

The analysis of seam and fastening technologies in water-sport suits shows:

Seam innovations: GBS, seam taping, liquid sealing, and thermal welding improve both water impermeability and strength.

Zipper technologies: waterproof polyurethane-coated types and ergonomically optimized diagonal front-entry systems enhance usability and sealing.

Cuffs and gaskets: latex, neoprene, and silicone options balance waterproofing with comfort.

Ergonomic integration: seams and fasteners must be positioned to accommodate slalom paddling mechanics.

For slalom paddlers, such construction technologies are as crucial as the base materials themselves, as they directly influence the suit's thermal safety, mobility, and long-term reliability.

**Conclusion.** Owing to its closed-cell structure and elasticity, neoprene remains the most suitable primary material for thermal insulation. However, aerogel- and graphene-enhanced composites represent promising directions for improving thermal performance.

Suit classification. Slalom suits are divided into three groups:

Wetsuits — flexible, but with a potential risk of overheating.

Drysuits — fully water-impermeable shells that require insulating underlayers; highly effective in cold conditions.

Hybrid suits — based on multilayer technical fabrics, providing high comfort and adaptability.

Water-impermeability technologies. Through lamination, advanced seam sealing (GBS, liquid rubber overcoats, thermal welding), and nano-coatings, manufacturers are enhancing durability, accelerating drying, and improving water-repellent performance.

Seams and fastening elements. Waterproof zippers, ergonomically positioned closures, and latex, neoprene, or silicone gaskets are key technological solutions that determine both safety and comfort.

Scientific–practical outcome. For slalom paddlers, it is necessary to develop a special “aeroprene”-based material package that meets three core requirements:

- effective thermal insulation;
- high abrasion resistance;
- ergonomic flexibility.

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