Technical Approach to the Overall Project

Hull Design

Last year's canoe, *Polaris* (UTCCT 2019), lost time on straight line sections, and paddlers reported that the canoe was awkward to paddle, particularly when sitting in the widest part of the canoe for the co-ed sprint. *704 Spadina*'s design put a significant focus on increasing straight line speed and decreasing the canoe's width to improve paddler ergonomics, and put a decreased focus on stability.

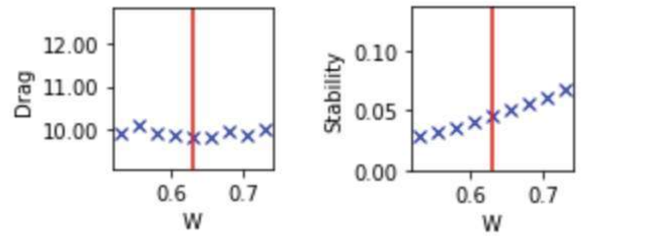
For *704 Spadina*'s design, the team made use of in-house software PANDA (UTCCT 2008) and POSSUM (UTCCT 2019). PANDA generates and analyzes thousands of canoe models within minutes, and POSSUM utilizes hyperparameter tuning to optimize for a set of performance criteria. Used together, the programs converge upon a set of design parameters that maximize the output value of a weighted table of performance criteria. (Guo 2017). The hull design team made six final designs and cross analyzed each design with the performance criteria used for the other designs, as well as that of past designs. The team consulted UTCCT alumni for feedback during design selection. The final design was selected based on its quantitative performance in the analysis, and for its qualities in the specific areas that were the focus of this year's hull design.

Table 4: Key Design Specifications of 704 Spadina and Polaris

Parameter	Polaris (2019)	704 Spadina (2020)
Length (m)	5.50	5.50
Bow Rocker (cm)	13.0	19.0
Stern Rocker (cm)	0	0
Maximum Width (cm)	75	66
Maximum Depth (cm)	35	35
Prismatic Coefficient	0.587	0.572

In response to the aforementioned difficulties experienced by *Polaris* paddlers, *704 Spadina* was designed to have a thinner actual beam width. In addition to increasing paddler comfort, decreasing the width of the canoe impacted several other performance indicators in our PANDA models, the most notable of which are shown in Figures 7 and 8.

Figures 7 and 8: Change in beam width (m) versus drag (Newton at 10 knots) and initial stability (off axis displacement, m) respectively



The red line on the graphs indicate the actual width of *704 Spadina* (0.66 m), and the blue markers indicate the drag/stability achieved by varying the width. The primary stability is shown to increase as the canoe width increases. While canoe width and drag has a less linear relationship, the final width approximately minimizes the drag experienced. This helps to meet the goal of increasing straight-line speed.

In previous years, UTCCT has produced consistently stable canoes, and consultation with past paddling teams, who were generally very satisfied with primary and secondary stability levels when racing, led us to prioritize increasing straight line speed and improving paddler ergonomics by altering the canoe width. While, the selected width does not provide the most stable canoe design, a narrower canoe allows paddlers to reach into the water more comfortably, without leaning off-centre. Paddlers that maintain a consistent centre of gravity will indirectly increase the stability of the canoe, and facilitate the paddlers to complete their entire stroke ergonomically.

Additional elements designed for *704 Spadina* include toe-blocks, bulkheads, and gunwales. Toe-blocks in our design serve ergonomic purposes rather than structural ones to help paddlers brace themselves for strong purchase in the water and efficient strokes with the added benefit of not significantly increasing weight or impacting structural performance, based on previous canoes.

Bulkheads are primarily intended to prevent water from entering the canoe. The gunwales on *704 Spadina* principally serve an ergonomic function, as team experience has noted that they make carrying the canoe much easier, with a lower chance of dropping and otherwise damaging the canoe in transport (Hwang et al. 2015). While gunwales can serve to add stiffness and strength to the canoe's cross section, *704 Spadina's* expected performance is not dependent on the presence of the gunwales.

Structural Analysis

The team utilised the Canoe Analysis Program (CAP), an in-house software developed in MATLAB® (MathWorks 2019), to analyse the effects of bending, gravity load from canoe, and paddlers with paddler loading factors for over 300 two dimensional traverse cross sections. The team determined the main contributors to shear and moment as the longitudinal and transverse bending from the load of paddlers, punching shear from paddlers pushing on the toe-block and leaning against the canoe body, as well as the hydrostatic forces of water on the submerged portion of the canoe. The wall thickness had the greatest influence on maximum stresses predicted by CAP, which were compared with experimental concrete strength results to determine the canoe's structural integrity.

After obtaining the stress profile and principal stresses of the canoe from CAP, the team incorporated them into the Mohr-Coulomb failure criterion to determine the region of no crack formation under any combination of stresses. This process was conducted to prevent seepage and damage from cracks that can form prior to concrete reaching its ultimate tensile strength, particularly under biaxial stresses from longitudinal and transverse bending.

In view of using an innovative approach to evaluate the formation of cracks at a microscopic level, the team utilised the biaxial failure contour proposed by Como-Luciano. It is established on the assumption that significant failure in the form of cracking occurs when the local maximum principal stresses around pores reach the tensile strength of the hardened cement paste, thus causing destruction in the concrete binder.

Structural Analysis Results

After running 270 loading cases with 2 and 4 paddlers weighing between 75-200 kg, CAP anticipated a maximum principal stress and minimum principal stress of 0.9369 MPa and 0.9199 MPa respectively. The stress envelope in Figure 9 concatenates the maximum stresses of the 270 loading cases to summarize the most extreme stress values at each location along the canoe. With an experimental tensile strength of 1.68 MPa that yields a factor of safety of 1.79 in addition to the paddler loading factor, the team has deemed the concrete mix sufficient to resist all loads on the concrete structure along with sufficient margin for some inconsistent quality control during concrete casting and sanding.

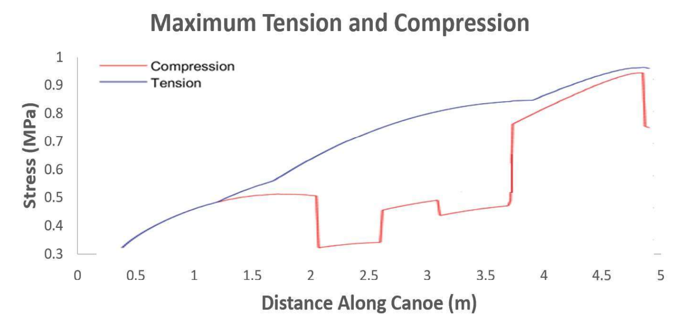


Figure 9: Tension and Compression Stress Envelopes of All Load Cases

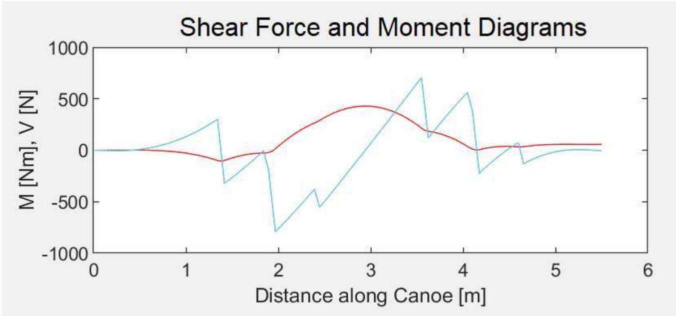


Figure 10: Shear Force and Moment Diagrams of Most Critical Load Case

In addition to stress calculations, primary reinforcement calculation was conducted under the assumption that the glass fibre mesh will be in a state of tension on the bottom of the C channel. The usage of short PVC fibres for secondary reinforcement allows the concrete to achieve a tensile strength of 1.68 MPa, and this empirical result is used to calculate the modulus of rupture. The calculated cracking moment of 2812 Nm and an ultimate bending capacity of 2233 Nm are well above an anticipated maximum moment of 400 Nm predicted by CAP (Figure 10). Since the capacity is more than one third greater than factored demand, the minimum reinforcement criterion may be waived (CSA A23.3 Clause 10.5.1.3). A large safety margin in tensile and bending capacity ensures that the team's structural strength is sufficient to resist all loading demands.