ALTA HYPERBARIC CHAMBER

Final Report

DEPD 3610: Studio 5 Design Implementation

Wilson School of Design 2020

Project Overview

Project Hyperbaric was introduced in spring of 2020, to the 2021 graduating class of the Product Design Undergraduate program at KPU. This group of ten, third-year students led by instructor, Sue Fairburn, and faculty at the Wilson School of Design ran for 9 weeks from January - March 2020.

The objective of this project was to design a portable hyperbaric chamber to be used to mitigate the effects of hypoxia associated with severe cases of HAPE (high altitude pulmonary edema) and HACE (high altitude cerebral edema) in high-altitude climbing victims by using pressurization to simulate a descent of 1500 to 2500m. The scope of this project included research, expert interviews, prototyping and testing as well as the production of a working final prototype.

ALTA HYPERBARIC CHAMBER

Current Problems

“There were so many people on Everest, many more than expected…we also had very unhealthy competition between very experienced guides and guides with no experience at all.”

Dawa Yangzum Sherpa (2019)

Defining the Problem

Changing Climate

As climate warming impacts historic weather patterns, climbing windows become more and more unpredictable.

Close Calls

As summit wait times increase, supplemental oxygen levels plummet putting climbers at further risk.

+

Popularity

As high-altitude climbing grows in popularity, Increasing numbers of inexperienced climbers are taking to the slopes.

Monetary

As tour leaders try to minimize costs by rushing ascents, the number of HAI incidents skyrockets.

+

Green Guides

As the popularity of mountaineering skyrockets, inexperienced guides flood the slopes to meet demand.

Inaccessible Innovation

Current portable hyperbaric chambers are heavy, expensive and hard to obtain as they can require a medical prescription and specialized training.

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Increased Danger

Injury and death at altitude are more common than ever before. With bottlenecked lineups near summits and trash heaps at basecamps, climbing over dead bodies is becoming the norm across Earth’s tallest summits.

Our Goal

To design an improved, weight-reduced, portable hyperbaric chamber, to be used by all mountaineers at altitudes above 2500m when needed.

Currently portable hyperbaric chambers exist, but are not popular with amateur mountaineers due to their weight and inaccessibility in the market.

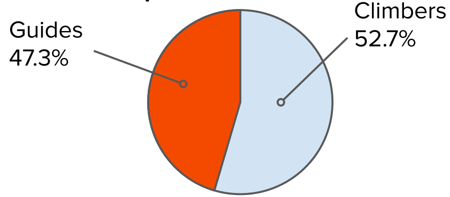
Persona

Gender: Male
Age: 34
Height: 5’10” (178cm)
Weight: 170 lbs (77.1kg)

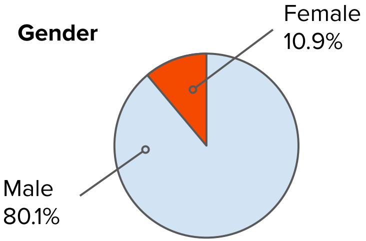
The following two figures, display basic equipment that mountaineers carry with them and sufficient outfitting while climbing. One of the heaviest components that mountaineers carry is the sleeping bag which weighs 4lbs.

Who’s Climbing

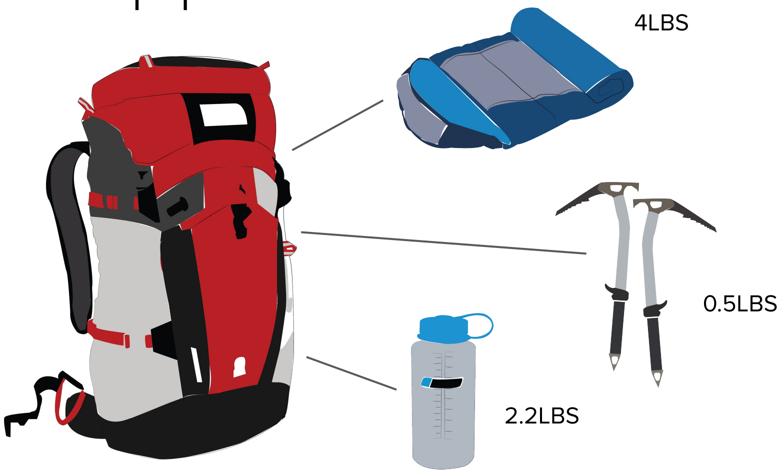
Climber Makeup



Gender



Heaviest Equipment



High Altitude Illnesses (HAI)

AMS (Acute Mountain Sickness)
Approx. 2500m
Time after ascent 1-2 days

Most common, not life threatening, headaches, dizziness, nausea, like a hangover

HAPE (High Altitude Pulmonary Edema)
Approx. 3000m
Time after ascent 3-4 days

Higher threat to life, cough, shortness of breath

HACE (High Altitude Cerebral Edema)
Approx. 3500m
Time after ascent 4-7 days

Higher threat to life, in and out of consciousness, uncoordinated, may lose ability to talk, acts drunk, confusion, hallucination

*altitudes listed are averages; AMS, HAPE and HACE can happen at various altitudes depending on the individual

Human Factors Considerations

- **Strength** - Airtight zippers can be difficult to open
- **Dexterity** - Users wear gloves
- **Humidity** - Damp gear leads to condensation
- **Pressure** - Ear can be damaged when pressure lost
- **Heat** - UV rays lead to heat build up
- **Size** - Able to fit the 99% male
- **Nutrition** - User may require food and water
- **Waste** - Need to facilitate bodily functions
- **Affordances** - Need to accomodate for unconscious patients

As 90% of climbers are male, and since women are statistically smaller than men, we were only concerned about fitting the longest person in our bag.

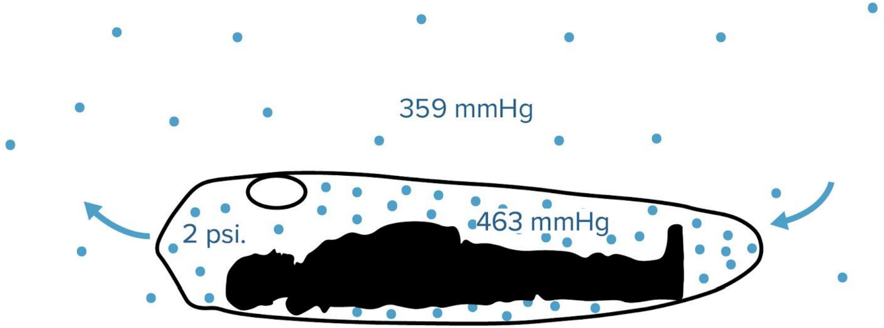

15.2% of recorded deaths are directly attributed to acute AMS
Himalayan Database, 2018

Simulating Descent

The chamber is pumped full of ambient air to 2psi, with a foot pump. The increase in air pressure inside the bag allows the victim's lungs to more readily absorb oxygen and potentially stabilize a victim of HAPE or HACE while they rest. The victim is removed periodically for assessment and/or additional treatment and may be treated from 1 - 8 hours until they are stable enough to descend or to be evacuated. Victims of HAPE typically need 2-4 hours while HACE may take 4-6 hours.

Actual Elevation			Simulated Elevation		
meters	*feet*	*mmHg absolute*	*meters*	*feet*	*mmHg absolute*
0	0	760	−1022	−3353	864
300	984	731	− 751	−2464	838
600	1969	705	− 495	−1624	837
900	2953	679	− 232	− 761	783
1200	3937	654	24	78	758
1500	4921	630	288	945	734
1800	5906	607	535	1755	711
2100	6890	584	798	2618	688
2400	7874	562	1054	3458	666
2700	8859	541	1310	4298	645
3000	9843	522	1555	5102	626
3300	10827	503	1805	5922	607
3600	11812	484	2053	6736	588
3900	12796	466	2299	7543	570
4200	13780	449	2544	8347	553
4500	14765	433	2787	9144	537
4800	15749	417	3028	9935	521
5100	16733	401	3268	10722	505
5400	17717	387	3505	11500	491
5700	18702	372	3741	12274	476
6000	19686	359	3975	13042	463
6300	20670	345	4206	13800	449
6600	21655	333	4436	14555	437
6900	22639	320	4664	15303	424
7200	23623	309	4890	16044	413
7500	24608	297	5113	16776	401
7800	25592	286	5335	17504	390
8100	26576	276	5554	18223	380
8400	27560	266	5771	18935	370
8700	28545	256	5986	19640	360
9000	29528	246	6198	20335	350

Adapted from Hyperbaric Mountain Technologies

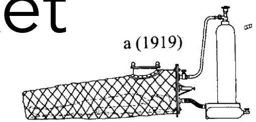


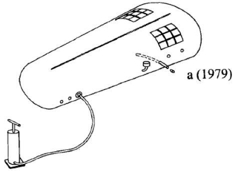
2 psi = 104 mmHg

359 mmHg ambient + 104 mmHg inside = 463 mmHg

463 mmHg equates to an elevation of 3975 m

Market





	H. Stelzner (1919)	H. Becker (1979)	Gamow (1987)	CERTEC (1989)	PAC (1996)	Ultralite Gamow (2011)
Purpose	Decompression sickness in divers	Treatment of high altitude illness	Treatment of high altitude illness	Treatment of high altitude illness	Treatment of high altitude illness	Treatment of high altitude illness
Length	N/A	2.00m	2.50m	2.20m	2.50m	2.1m
Weight	N/A	6.63kg	6.5kg	4.8kg	6.8kg	**3.49kg**
Features	1 window, ridgid hermetic seal opening at one end	2 windows, 2 zippers	2 windows, 1 longitudinal zipper	1 window, 1 zipper from top of head	4 windows, 1 radial zipper	2 windows, 1 longitudinal zipper
Usability	Used an electric pump and hose, excess pressure prevented using security valve	First made for treatment of high altitude illness. Has a conical shape and carry handles	2 relief valves. Slit opening and **straps restrict** ingress and egress. Comes with an **efficient pump.**	Double layer construction more durable. Zipper around top edge, opens like sleeping bag providing **better access. Poorly designed pump system.**	Mesh pocket for altimeter, visible in window, One automatic release valve, **restricted entry.**	**Lightest system**, same features as original Gamow, **not widely used.**
Price	N/A	N/A	$3512 CAD	$6377 CAD	**$1607 CAD**	$3741 CAD

Key Stakeholders

Capt. Chris Dare

CAF Officer,
Canadian Mountaineer
Interview via Skype; gave insight on climbing experience

Wendell Uglene

Manager of Research and Technology,
Mustang Survival Corporation
Interview in person; gave insight on construction and materials

Dr. Sanja Savic

President and Safety Director,
BaroMedical Hyperbaric Oxygen Clinic
Interview in person; gave insights on oxygen therapy and the effects

Elizabeth Rose

Author and
Canadian Mountaineer
Interview in person; gave insight on climbing experience

Maxim de Jong

Founder and President,
Thin Red Line Aerospace
Interview on site; brought forward project and gave insights on inflatable structures

Dr. Steven Roy

High Altitude Medicine Expert,
Remote Medical Trainer,
Wilderness MD
Interview via Skype; provided extensive knowledge about HAI and treatments

Dr. Anthony Chahal

President, Canadian Society of Mountain Medicine
Emergency Medicine Expert
Interview via Skype; provided feedback to our concepts with his experiences

Sue Fairburn

Professor,
Wilson School of Design
Provided guidance throughout whole project

Also special thanks to **Alex Biem** of Tangible Interactions, **Klause Kallesøe** of BaroMedical, **Stephanie Flynn** from KPU physics department

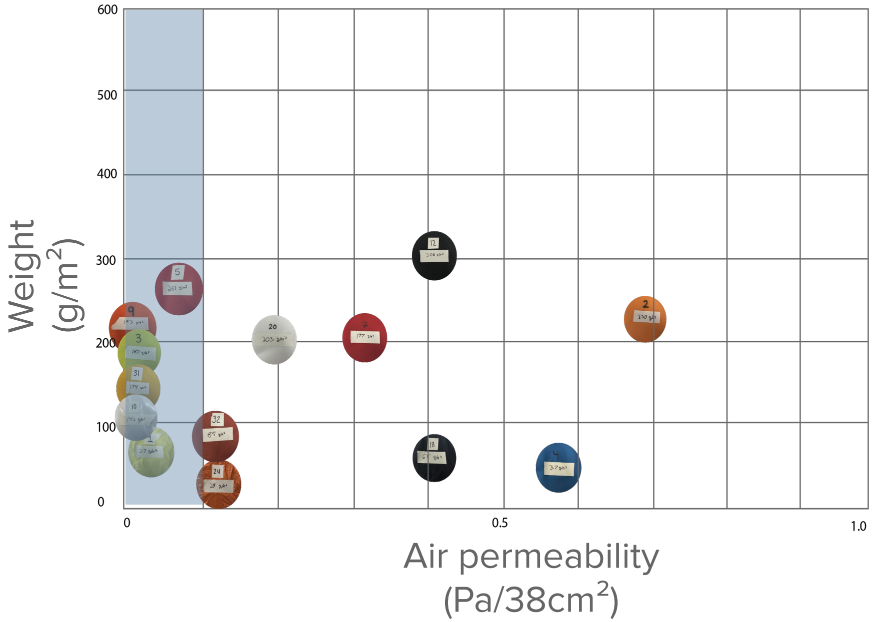
Design Requirements

- Airtight construction
- Holds 2psi

- Operable in extreme cold weather conditions
- Compacts into single human portable volume
- Functional in environmental conditions to -40^{o}C
- Provides clear line of sight to patient while in use
- Provides 180^{o} access to patient's head/neck when open
- Permits egress and ingress for 99% winter-clothed male

- Lighter weight than current market by >10%
- Securable to terrain
- Uses intuitive closure system
- Pictoral or multilingual easy to follow instructions
- Does not require extensive training to use

Material Selection

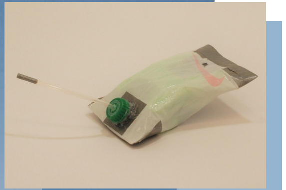


We chose 38 initial materials for testing and weighed them all. We then tested for air and water permeability and graphed our results to decide what materials to do further testing on. We found the most important factor of material choice to be how well the coatings bonded, so we picked the materials with bondable coatings and did further testing that including abrasion, tear, and seam strength. Our top material option for the chamber ended up being #9 and #25 (both PU coated nylon), as well as #23 (clear PVC). For external components we selected #37 (nylon ripstop) for its light weight and strength.

Development Map

Our process consisted of lots of iterative prototyping and testing, we evaluated ideas with matrices and our design requirements in order to come to a resolved solution.

ALTA Pump Development



PUMP-SPG-01

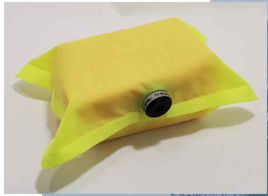
This prototype explored the initial concept of using open celled polyurethane foam as a spring to inflate and decrease weight of the pump.

PUMP-SPG-02

This prototype explored industrial fabric casing, larger foam and industrial check valves donated by Mustang Survival.

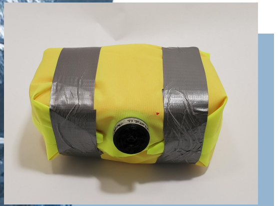
PUMP-SPG-03

This prototype explored the fluoro nylon fabric, heat pressing the seams together and intentionally delayed inflation time.



PUMP-SPG-04

This prototype explored different pattern dimensions for a more efficient construction.



PUMP-SPG-04-ALT-01

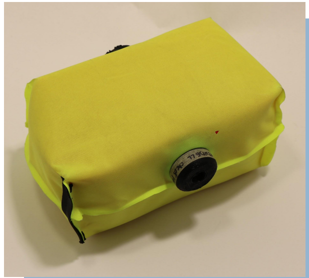
This iteration of PUMP-SPG-04 explored the removal of unused space within the pump, and decrease fabric usage, to create a more efficient output.

PUMP-SPG-05

This prototype explored the adaption of the PUMP-SPG-04-ALT-01 pattern, attempting to alter the form.

PUMP-SPG-04-ALT-02

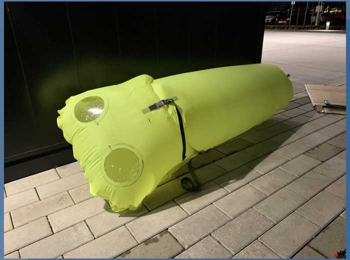
This iteration of PUMP-SPG-04 explored the refinement of the pattern and construction process while simultaneously maximising the efficiency of the output volume.



Large scale prototypes

FLSC-CYL-01

Insights/lessons learned: Roll top too long to keep airtight, takes 2 people to roll the roll top
Tried to put a cardboard tube to act as a clip to keep roll top closed, tube snapped in half during testing and would not be easily transportable
End caps hard to attach to cylinder, because of smaller radius
Not able to inflate to 2psi
Able to roll the roll top 6 times



FLSC-TPR-01

Insights/lessons learned: Was able to heat seal edges of roll top together, more airtight
Needed a buckle across top middle to prevent roll top from unrolling
Windows too close to top when inflated windows did not allow for adequate 180 view
Lots of space by feet
Buckling along seam at head
Leaking a little air by release valve, concerns of tearing fabric
Able to roll the roll top 8 times

FLSC-BSB-01

Insights/lessons learned: Not ideal to have buckles underneath, vulnerable to damage
Without additional strap roll top started to unroll
Entire scale too small, especially entrance
With extra strap able to inflate to 2psi

FLSC-TPR-02

Insights/lessons learned: Plastic D-ring broke during testing, replaced with heavier strap adjuster, broke anyways
Buckle broke during testing, buckle too weak
Replace buckle with carabiner, placement of loops too close needed, created too much tension needed to be further apart
Inflated to 2psi only with carabiner
Was able to roll the top top 6 times

ALTA System

Alta Hyperbaric Chamber

Alta is a lightweight and portable hyperbaric chamber for use in high altitude. At a total system weight of only 5 lbs, recreational mountaineers and guides can comfortably carry it with them on expeditions. It has been designed to be the easiest chamber to use and operate to decrease the number of deaths occurring in field.

Relief Valve

- Seal breaks at 2 psi
- Allows internal air to exit the chamber and release CO_2 buildup
- Permits fresh air flow through chamber

Closure

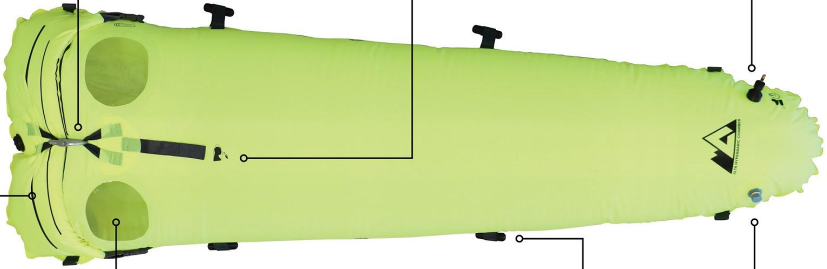
- Strong carabiner closes the roll top
- Available and easily replaced in the field if needed

Pull Tab

- Used to lift the bag off of the victims face inside the bag
- Flat design does not afford to be pulled on with much force

Intake Valve

- Colour coordinated to match pump for ease of setup
- Pictograph indicates duration between pumps of air



Roll Top

- Numbered lines to indicate the amount of folds
- Pictograph depicts the direction of rolling
- Rolling the opposite way does not impair function

Windows

- Large enough to allow visual communication with victim inside
- Attendants are able to see through the bag to other side

Toggles

- Allows users to pull the bag onto an unconscious victim
- Webbing is long enough to accommodate a 99th percentile hand in mittens
- They are designed as an anti-affordance to lifting

Relief Valve

- Used to slowly deflate the bag so the person inside can equalize their ears to avoid damage
- Cap can't be removed to prevent rapid deflation

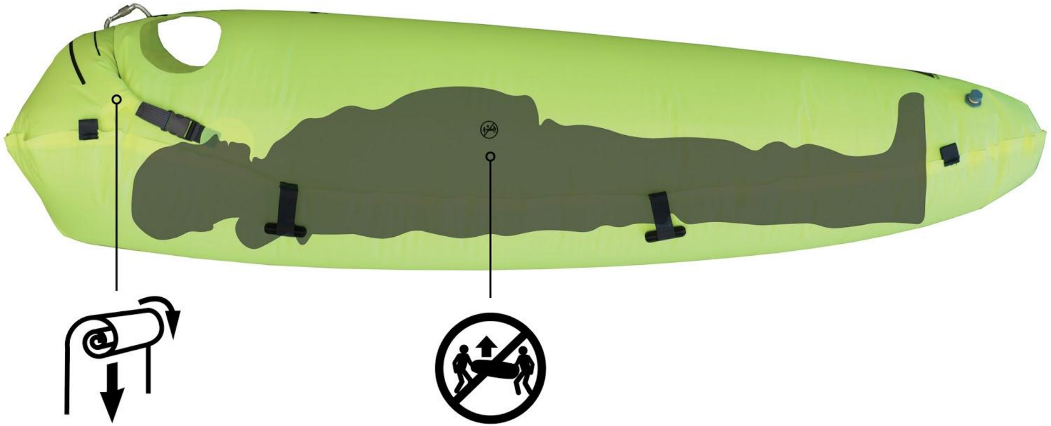
Specifications:

Inflated Dimensions:
Length: 89.5”
Width: 26.5”
Weight: 4.22 lbs.

Case Weight: 0.44 lbs.

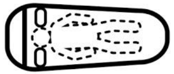
Pump Weight: 0.46 lbs.

Total Weight: 5.12 lbs.



Sizing

- Chamber can easily accommodate a 99th percentile male
- Victims can align themselves with windows to feel more comfortable and less isolated



Alta Carry Case

Alta's carry case is a lightweight and convenient way to protect the chamber when not in use. The chamber rolls up to fit securely inside and the instructions make it easy to use and pack up. The carry case can be carried on its own or attached to other gear with the full-length handle.

Dual Buckle Closure

- Compresses and secures chamber inside case

Handle

- Webbing strap functions as carrying handle and allows securing it to other gear

Instructions

- Pictographs indicate how to roll the chamber and store in case

Alta Pump

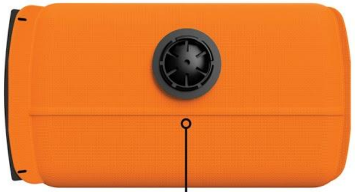
The pump fills the chamber to pressure with fresh air, while providing the user visual feedback for how fast to inflate. At only half a pound, it is much lighter than the competition while increasing output per compression.

Output Valve

- Colour coordinated to match the intake valve of the chamber

Timing Indicator

- Strap becomes taut after 7 sec. indicating that the pump should be compressed again

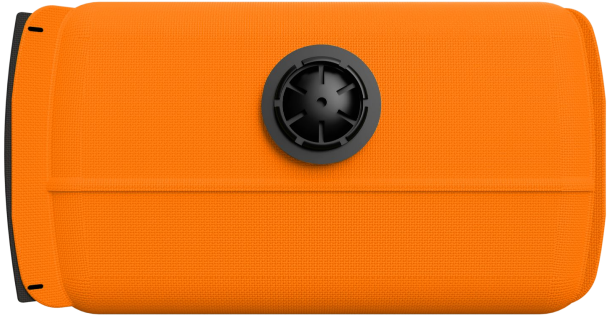


Intake Valve

- Brings fresh, ambient air into the pump to fill the chamber

Alta Pump Mechanics

Uses open cell polyurethane to act as a spring to re-inflate the pump



Form of pump innovates with the volume of enclosure to maximize air output

Intake Check Valve bring in ambient air and keeps it inside the enclosure

Output check valve pushes air out of the enclosure while preventing it’s return