Spacesuit Equipment Considerations

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Abstract

At Mars Desert Research Station (MDRS) in Utah, I experimented with different gear and weight configurations with the simulated space suit. Since the suits have minimal storage pockets and a simulated life support backpack, arrangements have to be made with chest-packs, belts, holsters, pouches, and so on. The helmet and backpack of the suit design shifts the person's center of gravity (CG) backwards and upwards. This is counterproductive, because the rough terrain and climbing situations make it desirable for the center of gravity to be at a natural belt-height or lower if possible.

This paper describes MDRS suit gear location options on current and future suit designs. The long term goal is to maximize both the fidelity of the MDRS and other analog suits to what will actually be used in space, while also maximizing science usability relative to gear access, comfort, and safety.

Simulation Spacesuit Pain Points

The MDRS Extra Vehicular Activity (EVA) simulation suits are a paradox because they have to both enable and disable the user. To be a realistic simulation of working on Mars, the suit must have the following negative traits:

- Limited hearing due to helmet and cooling fans
- Limited visibility due to helmet being fixed to shoulders rather than head. There are also factors of faceplate glare, scratches, and fogging.
- Limited mobility due to bulky backpack, coveralls, gloves, and boots.
- Limited tactile sensation and dexterity due to gloves.
- Minimal sense of weather due to isolation of helmet (wind and temperature are difficult to determine intuitively, especially in high desert without vegetation to show wind direction or make noise)
- Increased body temperature due to helmet, coveralls, and gloves in sunny conditions.
- Offset center of gravity due to helmet and backpack.
- Limited ability to carry other gear.

The suits also have the following enabling qualities:

- Radio communication allows exchange of verbal information over medium distances.
- The coveralls and leg covers protect clothing from dust, mud, and wear in the desert environment.
- The backpack straps and belt offer some attachment points for gear bags and equipment.
- The forearm backs offer space for attachment of driving mirrors, GPS receivers, and any touch-recording equipment (control buttons, notepad, smart phone, etc.)

- Before capacitive displays became the norm, crews would attach a stylus to the middle digit of the index finger of the dominant hand to have a way to push buttons on GPS receivers and other gear. This also allowed easier extraction of rocks from mud and any other function where the heavy ski gloves restricted dexterity too much to be effective.

Overall, the suits limit the time and energy that can be put into pure exploration. Field work is constrained due to the limitations imposed by the Mars analog simulation. Conversely, because the user feels to some degree “indoors” while in the suit, it can also lower inhibition and feelings of exposure when out on extended EVAs. They also protect from weather, dust, and occasional mud when working outdoors.

Suit Success Criteria

An analog spacesuit has performance criteria to determine how good it is at the job of simulation. A notional key performance indicator (KPI) list is as follows:

- Improve the accuracy of the suit in fidelity to an actual Mars spacesuit on the surface of Mars. Is the user experience as close as possible to the real thing?
    - Are the user interfaces with the suit accurate?
    - Are the suit/user interfaces with the surface/weather accurate?
    - Are the suit/user interfaces with the other crew accurate?
    - Are the suit/user interfaces with tools, equipment, instruments, and vehicles accurate?
    - Is the mass accurate to a low-gravity environment (center of gravity shift)?
    - What is the relative difficulty for a given user of feeling/functioning as if they are actually on Mars while using this suit? In other words, is suspension of disbelief easier or more difficult in this suit relative to other designs, all else being equal?
- Improve the ability of the suit user to do science and engineering work safely.
    - Can we maximize the amount of gear that can be carried while minimizing the discomfort of doing so?
    - Can we do so while making the suits as safe as possible in steep terrain?
        - Can we minimize the probability that the user will fall or otherwise loose balance while climbing or operating an ATV?
        - Can we minimize damage to the user, suit, and gear in the event of a fall?
- Can we do all this at the lowest cost in time, money, and maintenance as possible?
    - Can we find a point of lowest cost/greatest durability for each gear item in place?
    - Can we make things field-maintainable to the greatest degree possible?

- Should we consider modular components, 3D printed elements, or other sub-projects to enhance the suit durability, utility, versatility, and realism?

Case History: MDRS Suit 1.0 and 2.0

The table below compares the suit I used on crew 32 in 2005 versus the crew 124, field season 2012 suit.

Original MDRS Suit (Crew 32)	Current MDRS Suit (124)	Impacts of Variation
Suit Coverall • Custom canvas coverall, • Zipper in back with pull-line • Velcro crew badge location (photo ID, crew immersion) • Pockets and design inspired by Apollo suits – more "photogenic" for press visits	• Commercial off-the-shelf canvas coverall • Zipper in front • Fewer pockets	• Visual and psychological analog suffers • Cost and labor dramatically reduced by not repeating custom work.
Helmet • Combination of off-the-shelf parts, plus a durable collar • Fan ports into helmet with ducts to blow air across face or faceplate. • Push-to-Talk button for radio included in collar • Later suits allowed for hydration pack water lines for bite valves	• Push-to-talk button removed • Users must "break sim" to either yell into radio or hold under helmet collar • Some air vents were damaged or improvised	• Visual and psychological analog suffers • Cost and labor reduced by not repeating custom work with button
Boots • Paratrooper boots provided by Mars Society • Lead weights aided climbing by lowering the overall center of gravity	• Bring your own boots	• Better fit, comfort, and hygiene versus shared boot
Gloves/Stylus Interface • Heavy ski gloves provided. • Many crews would duct-tape a nail or stylus to the index finger to push buttons and pry rocks.	• Bring your own gloves	• Visual and psychological analog suffers. • Allows experimentation with various glove options such as mechanics gloves.
Gaiters (Leg Covers) • Standard off-the-shelf gaiters used.	• Same, but with some variations in design	• By disguising the user's personal boots, increases fidelity overall.
Backpack/Harness • Pack-frame with straps, belt. Combined with collar for mounting helmet.	• Lighter batteries?	• No change.

Shift in Techniques: MDRS Suit 1.0 and 2.0

Original MDRS Suit (Crew 32)	Current MDRS Suit (124)	Impacts of Variation
• Use of duct tape "belt" to adjust suit leg length and keep strings in place.	• Rarely done, due to more suits in more sizes.	• Easier to don/doff suit • More realism
• Use of yarn-like strings tied to gear and suit belt to keep dropped items from being lost due to lack of ability to see/hear/feel the gear hitting the ground or falling from the suit.	• No longer standard practice.	• Faster EVA Prep/Return. • Minimal loss of actual gear, possibly because there are no pockets to be trusted and all gear is zipped in when not in use.
• Zipper on spine means crews very unlikely to attempt to fully suit themselves.	• Zipper in front means crews generally suit up independently until it is time to put on air hoses, which are still difficult to line up without assistance	• Crews more likely to put on coveralls just for protection and warmth outside (engineer, astronomer in particular).
• Ski gloves only • Nail or stylus often taped to index finger second digit to aid in pushing GPS buttons, digging out rocks, opening bags, and so on. It helped compensate for the lack of manual dexterity with the heavy glove.	• Personal gloves are usually much thinner than ski gloves. • Occasionally partial sim break for sterile sampling with latex gloves and use of multi-touch tablet interfaces.	• Sim realism reduced. • This may actually be part of the reason less gear is accidentally lost in the field (see strings, above). It is much easier to feel if a camera/hammer/etc is secure in work gloves than ski gloves before continuing with movement.

Impact of Suit Design Changes

While the new MDRS analog suits take less time and money to maintain than the original suits, there is lower fidelity in the simulation. This requires greater crew self-discipline to avoid "breaking sim" (intentionally doing things that would not be survivable were the person actually in a spacesuit on Mars) when unnecessary. That said, MDRS has applied lessons learned and shifted the parameters of the experience over the dozen years of operation, so that the facility is not simply repeating the same work year after year. The current suit has different parameters from the suit before it, and will be replaced starting next field season.

Ongoing Issues with MDRS Suits

There are some issues that have never been solved in the history of MDRS sim-suits, in large part because the suits themselves are not the problem.

MDRS Helmets

MDRS Helmets are made inexpensively, and seem to be a frequent failure point. The plastic faceplate is frequently scratched and occasionally shows signs of impact. They were originally to be worn at all times, but can now be swapped with proper safety helmets on the ATVs if the rider chooses to do so.

Faceplate Ergonomics

Once the human mind becomes skilled in the use of a given tool and task, the mind focuses on the work rather than on the tools. If a new limit is placed on the work environment, that limit may be unintentionally ignored due to the muscle memory or skill repeatability of the use of those tools. This is often a safety issue in factories, where new guards are ignored on machinery out of force of habit. That said, it has a subtle impact on MDRS work where intuitive tasks must be adapted to deal with simulation.

It is noteworthy that the impact point on many helmet visors is exactly where you would expect it to be if a previous user had been lining up a rock hammer between their dominant eye and the rock to be struck. This is human nature without a helmet. People adjust their kinesthetic limits of motion for the tool so that under normal circumstances, most people do not hit themselves in the face when they maximize the backswing with a hammer. With the helmet, users adjust it a second time to compensate for the faceplate.

There is a similar tendency with archery. If an adult is handed a child's bow, they will naturally look down the arrow itself to the target. If you had them one that is the correct size, the bow is drawn over to the shoulder instead of the face. Similarly, an MDRS crew member may tap the faceplate, realize the issue, and then remember to use the hammer at an unnatural, over the shoulder backswing or shorter, visually-aligned stroke that stops short of the faceplate.

The helmets are inexpensive because they break often, and they break often because they are inexpensive. They will probably have to remain so until some exotic transparent materials technology allow an affordable helmet to routinely be hit with the sharp end of a rock hammer.

Problem Areas for Spacesuits (Real and Simulated)

Helmet Mounting Issues

With most pressure suits, helmets are typically mounted to the shoulders with the head rotating freely within them. This is the opposite of most protective helmets, which are mounted to the head and allow the head (and field of view) to rotate freely at will by the user. Consequentially, a spacesuit field of vision is more restricted, and cannot be compensated for with head movement. There are exceptions, such as the David Clark Model 1030 pressurized flight suit for the SR-71 reconnaissance aircraft. This suit is only pressurized during emergencies, so it does not have pressure-differential stresses to overcome in normal use. The helmet is mounted to the head, and the collar ring allows the head to be turned. With no pressure differential, this is trivial. If there is an emergency and the suit is pressurized, the helmet becomes very difficult to rotate. That said, the Gsk-6A Russian equivalent high-altitude helmet may form a suitable model for future MDRS helmets, because the faceplate is a simple curved surface instead of a compound curve.

The issue preventing head-mounted space helmets seems to be the fact that the neck contains flexible and delicate vertebrae and relatively weak, whereas the interface with a pressure suit tends to be a two-dimensional ring which may allow the head to rotate but not to angle in elevation. Futuristic "skin suits" still use the fixed, shoulder-mounted helmet because applying excessive pressure to the neck is basically the definition of being strangled.

Helmets and Psychology

Because humans have a tendency to emote non-verbal communication through subtle head movements, the shoulder-mounted "bubble" helmet is probably a permanent option for explorers. It allows unrestricted movement in the neck and head, even with the limited field of view. Psychologically, we tend to observe our own actions and file our memories based on what we saw ourselves doing rather than the actual thought processes behind the actions. This is a key aspect of therapists driving patients to "fake it until you make it" – which is to say, the patient is instructed to act like the person they want to be until they more naturally follow those habits. This works because the mind forms memories based on what a person observes of their own actions, more so than why they did those actions. If a suit forces the user to move more robotically than would be natural, we not only loose a critical aspect of non-verbal communication with other crew members, but we may potentially also loose that "communication" with ourselves in forming memories. The human sense of wonder in exploring a new world may be subconsciously diminished if suits force explorers to move like robots rather than humans.

On the subject of spacesuits and non-verbal communication, a movie in the 1990's added LED lights inside the helmets to show the faces of the actors so that the audience could see them act. NASA loved the idea, because helmets at that time were designed to maximize the visibility of the user outward and were therefore designed to cut internal glare. Astronauts could not see each other's non-verbal communication when face-to-face on ISS EVAs.

Glove Issues

Modern smart phones, tablets, and other GPS and camera data logging devices often require multi-touch support. The use of a stylus is limited when needing to zoom into or out of a digital map. There are thin gloves that have chemically-dipped fingertips that allow the use of tablets and smart phones. A future Mars tablet must support either a stylus or the suit gloves should have compatible fingertips. If a stylus is chosen, the user interface must be fully functional without multi-touch to be used in the field.

Gloves and Pockets

Naturally, any pocket or pouch must be accessible with a thick glove, resist loss of equipment, and resist contamination of equipment. The pocket must also provide enough tactile feedback to the hands to show that the pouch is actually closed, so that gear does not fall out. Zippers are ideal for this because the position of the hand tells the user if it is closed, and the seal is fairly solid. In an actual spacesuit, this would probably be impractical due to dust and grit. Velcro or magnets would also attract contamination on a real surface spacesuit. To deal with the inability to see pouch pocket flaps, a clip that is easily felt as locked or unlocked could be used.

An ideal spacesuit would have an RFID scanner in the glove, and all pocket-sized gear would include RFID tags. The user could determine what pocket held something from inventory by asking the onboard computer, or simply wave their hand over the pocket and see the contents on a heads up display. The system could also flag if a pocket were open or closed, and if all gear was returned prior to moving to the next site.

Backpack Issues

Life Support

A backpack is a natural way to carry a large amount of equipment over a long distance. For any spacesuit, that space is taken up with the life support backpack. It cannot be readily accessed by the crew member wearing it. Apollo compensated by putting chest ports for air hoses that could be used with the backpack or other equipment. This simplified ascent situations. It also allowed them to connect two suits to a single backpack in the event of a field failure.

Proposed MDRS Gear Solution Set

This section runs through the options for carrying gear on the current MDRS suit. These methods can be transferred to future spacesuit designs, though the examples will be specific to MDRS and other analog studies. It will also touch on slight modifications to the MDRS suit that could be introduced with future equipment maintenance.

Proposed Use of MOLLE system for MDRS

MOLLE (Modular Lightweight Load-Carrying Equipment) is a NATO field gear packing system where equipment can be mounted to vests, rucksacks, and so on. With MOLLE, some load bearing gear (vests, rucksacks, leg covers, equipment covers, etc.) is covered with a series of heavy nylon strips. These are sewn into the surface of the bag or vest at regular intervals, allowing gear to be hooked with special clips or snap-over straps through these loops and mounted to the surface. This allows modular gear placement on top of other gear. While most sizes are for military and police use (ammunition magazines, flashlights, etc.), there are hydration packs, first aid kits, and other equipment pouch sizes that have utility for an MDRS application. Correctly-sized pouches can be found for sterile sample containers, cameras, and so on. Loops can be attached for rock hammers and other tools and sampling gear. MOLLE is slowly transitioning into conventional camping gear and backpacks.

In the short term, a tan MOLLE vest and belt/leg systems could be used with existing MDRS equipment. This would allow integration testing with the backpacks, chest straps, and other gear. This would be worn over the jumpsuit but under the backpack straps. Enough loops would be exposed to allow attachment of gear to the chest, belt, and hips. People coming to MDRS would simply purchase the correct size MOLLE pouches for their field gear, and would use whatever vests and leg covers were on site. Since this would not be used in all cases by all crew members, two to four MOLLE vests or other base systems would probably be adequate.

In the long term, MOLLE straps could be integrated directly into MDRS gear. A series of loops on the outside of the backpack (clear of the fans) would allow long bundles to be carried externally, such as a small field-operated RPV, extendable antenna or tent-like structures.

General Physics of Gear Location

Some of the same rules apply to human load-bearing capacity as apply to vehicle stability.

- The closer a load is to the center of gravity, the higher the load that can be carried comfortably. This is also true of average loads distributed around the center of mass.
- In level terrain, loads can be stacked vertically close to the center line from the center of gravity – in other words, stacked on top of the backpack by the helmet.
- A high center of gravity while climbing may dramatically destabilize the load and make the wearer loose balance more easily.
- As with any structure, loads near the extremes (forearms and shins) will require greater energy to move and balance than loads close to the center of gravity. They provide more momentum once in motion and inertia when stationary.
- The core frame, in the case of the human body, is the hip. It is at the center of gravity, and allows for loads on the upper body to be transferred to the legs. A good backpack has an excellent belt and frame to shift as much weight away from the spine and directly to the hips.

Gear Packing Options, Capacities, and Limitations

This section runs through nearly every human equipment configuration, with the capacities and restraints on loads in those areas. It then walks through possible solutions for carrying gear and the types of gear most suited to those locations. These lists assume that the crew member is wearing a life support backpack and helmet. For this reason, head-mounted loads and tump lines are not considered feasible.

Forearms

Early MDRS missions occurred before the smart-phone era, when GPS systems were typically separate and involved buttons. Therefore, taping a GPS to the forearm was a common tactic for accessibility and visibility. A stylus was taped to the index finger of the opposite (left) hand to facilitate pushing buttons. A mirror was fixed to the left arm for ATV EVAs so that the right hand could remain on the throttle while checking behind for any issues with those on other ATVs. Buttons for controls on spacesuit forearms date back to science fiction movie spacesuit concepts from the late 1960's.

Forearm Location Parameters

Visibility	Very high	**Volume**	Low – flat electronics, mirrors, gear
Accessibility	Very high, one hand	**Load Limit**	Very Low – under 500 grams
Comfort	High	**CG Impact**	Slight improvement if climbing, Adding weight to forearm makes all activities with arms require more effort.

Forearm Equipment Configurations

Method	**Mount Description**	**Equipment Options**

Velcro wrap-around Strap	Tape or Velcro-strap equipment to the forearm.	• Small electronics, GPS, etc. • Rear-view mirrors for ATV driving
MOLLE forearm shield (proposed)	Use a MOLLE strap "bracer" that wraps around the entire forearm, and attach small equipment pouches to the loops on the outside of it.	• Small tools such as sampling instruments • Drill bits • Electronic control panels (custom)

Lower leg

This would basically be any load mounted from the knee to the ankle. While a pocket at this location was on the Apollo surface spacesuit, fatigue from walking in low gravity was not an issue. Conversely, reaching pockets with an inflexible suit was a bigger problem. These pockets were mainly used for contingency samples, where a small load was placed there early and ignored from that point forward. Placing a sample at the shin also helped lower the center of gravity slightly.

Lower Leg Location Parameters

Visibility	Low	**Volume**	Low – flat equipment
Accessibility	Medium to Low. Likely to get dirty.	**Load Limit**	Low – under 500 grams for hiking Under 1 kg for climbing
Comfort	Very conditional on climbing (high) versus hiking (low)	**CG Impact**	Improvement if climbing, Adding weight to the shin makes every step while hiking more difficult, but lowers center of gravity while climbing.

Lower Leg Equipment Configurations

Method	Mount Description	Equipment Options
Velcro wrap-around Strap (standard)	Used for boot covers currently – no storage space.	Not applicable.
MOLLE shin shield (proposed)	Use a MOLLE strap "shin guard" that wraps around the entire shin, and attach small equipment pouches to the loops on the outside of it.	• Small tools such as sampling instruments • Drill bits • Any gear not damaged by dust or mud.

Belt/Side

The MDRS backpack belt allows some gear to be carried on the hip. This allows an SLR camera bag with telephoto lens to be readily accessible. A holster for a hammer drill or other tools can also be mounted the same way. The main problem is that with the limitation of visibility with the helmet and the limitations of tactile feedback from the gloves.

This can take the form of a belt pouch, a holster, or a leg/belt attachment point for larger gear, provided it does not overly restrict movement during hiking.

Belt/Hip Location Parameters

Visibility	Medium	**Volume**	Medium – roughly 10 by 20 by 20 cm
Accessibility	High – both hands	**Load Limit**	10 kg if off-set on opposite side (5 kg each side) 3 kg if on one side only.
Comfort	High	**CG Impact**	Slightly to one side – may offset with another pack on other side.

Belt/Hip Equipment Configurations

Method	**Mount Description**	**Equipment Options**
Belt pouch (general purpose)	Camera bag or similar bag with belt strap that can fit on the backpack belt near the hip.	• SLR Camera bag with separate telephoto lens. • Similar bag for sample containers, etc.
Belt pouch (custom purpose)	Typically, this would be a wilderness first aid kit or some other emergency gear	• Wilderness first aid kit. • Equivalent tool bag or other rarely used equipment.
Belt Holster (Tested, MDRS 124)	Typically a power tool holster can be used with the backpack belt or a separate belt worn under the backpack belt.	• Power tools (hammer drill, etc.) • Rock hammer clip
Upper Leg MOLLE Shield (proposed)	This is an off-the-shelf MOLLE panel that straps to the upper leg in two locations and connects to the belt at the top. It has a series of MOLLE loops on the outside	• Good for small loads or external pockets with light to medium weight gear. • The belt handles the load, shifting the load-bearing surface to the hips rather than the leg.

Front Vest and Backpack Chest Straps

The weight of the backpack can be offset by securing a hydration pack through the chest strap on the backpack. If the hydration pack also has outside pockets, it can give ready access to tools and sample containers.

Chest Location Parameters

Visibility	Limited by helmet.	**Volume**	20 cm wide, 10 cm deep, 40 cm long
Accessibility	Very good with both hands.	**Load Limit**	Depends on rig – probably 10 kg Greater if looped into backpack straps than if mounted independently.
Comfort	Enhanced if offset against backpack. Avoid hard edges around sternum for safety. Avoid bouncing loads.	**CG Impact**	Shifts forward beneficially for walking, but moves further up body, which is not as good for climbing.

Chest Equipment Configurations

Method	Mount Description	Equipment Options
Hydration Pack with pockets (Current)	Run the arm straps and/or storage strap at the top of the bag through the chest strap on the MDRS backpack.	• Pockets allow room for sampling gear, sample containers, and anything up to the size of a full-size iPad.
MOLLE Vest (proposed)	Simple vest with MOLLE straps across the chest down to the belt area. Typically the shoulders are re-enforced to deal with backpacks and help distribute weight better.	• Allows many small pockets in any area not covered by the straps.
Advanced Sim Chest pack (long term proposed)	Place the fan, battery, and air hose gear in a chest-pack rather than a backpack. If possible, use lithium power tool cells for power to allow field swapping and lower mass. Allow a MOLLE space for hydration pack as well. Configure so that a full backpack may also be worn.	• Can maintain sim while carrying heavy backpack in advanced studies, such as early NASA robotics studies at MDRS. • Drone control /monitoring tablet. • A uniform shelf specification could be published, allowing future crews to design and construct mission-specific add-ons. This space is small enough for a 3D printed box for electronics or other custom field gear.

Possible Issues with Chest packs

Anything that might seriously injure a user by cracking the sternum in a fall or collision should be avoided. Any chest pack should have the hydration pack against the body if possible to distribute a forward impact rather than concentrate it. If the hydration pack is above the load, hard edges of equipment against the center of the chest should be avoided.

If a configuration is made universal to a mission or location, avoid weight loads and placement that will negatively impact comfort for different body types that will be on that mission.

While the accessibility radius of the MDRS suit is restricted only by a canvas coverall, actual pressure suits are not so flexible. If the ability to bend the elbow and shoulder is too restricted, the pockets on one side of the body may only be accessible by reaching across the sternum from the opposite arm. The flaps on the pockets should reflect this issue. A high-fidelity simulation may configure pockets this way.

The Emergency Chest Pack Concept

For a true spacesuit, the inability to swap consumables such as air tanks, carbon dioxide scrubbers, and batteries may necessitate an emergency chest pack or field-removable backpack. This would have modular batteries, small liquid oxygen bottles, and efficient scrubbers that could be plugged in by the user without assistance.

For a real spacesuit, having the option to replace a large, long duration Apollo-style life support backpack with a small, short duration but field-serviceable chest pack may be very useful. A chest pack could be designed with modular swaps of batteries, carbon dioxide scrubbers, and liquid oxygen tanks. The batteries would be the same models as those used in power tools, research equipment, and drones, giving a larger pool of resources to be used for work or emergencies. A narrow suit without the backpack would be much easier to use in escape situations or maintenance work in narrow spaces. An explorer with both packs could operate much longer in the field with a combination of field-replenished and bulk life support equipment.

An MDRS equivalent could be made with a single large front fan, small box, and swappable power tool lithium batteries. It could include a hydration pack space for a user-provided water bladder. It could be designed with a space for user-provided field gear and parameters that allow boxes to be 3D printed or built for electronics or storage at that location.

MDRS Backpack Modifications

The MDRS backpack in its current form could have a custom-made MOLLE cover strapped to the top of it. This would allow some lightweight gear to be attached to the top, sides, and back of the MDRS suit. This should not be made standard unless it is done in the same color as the backpack. An interim solution would be a fabric cover for the top of the backpack that would incorporate the loops. Such a cover would have to be strapped around the pack to keep it from falling off. Any such gear carried on the backpack would have to remain clear of fan intakes. It should also not block the large numbers on the back of the backpack.

For safety reasons, we should not encourage large heavy items to be strapped to the back of the backpack. This will shift the user's center of gravity too far rearward for safe climbing.

Top/Sides/Bottom of MDRS Backpack, Location Parameters

Visibility	Zero	**Volume**	Top/bottom – 10 cm deep, 30 cm wide, 20 cm tall. Sides – 10 by 10 cm wide/deep, 60 cm long
Accessibility	It is possible to reach to the top or back lower sides of the pack, provided it can be removed and replaced blind.	**Load Limit**	5-8 kg for top of pack. Sides and bottom should be limited by the structural strength of the MDRS backpack box.
Comfort	Relatively high, but when combined with helmet, fine tuning of the helmet position would be of benefit.	**CG Impact**	• Shifts rearward, so keep loads to a minimum for climbing • Shifts upward if on top of pack, so would prefer bottom of pack. • If loaded heavily on one side, balance load to other side as well.

Top/Sides/Bottom of MDRS Backpack, Equipment Configurations

Method	Mount Description	Equipment Options

Top of pack	Some crews mount the hydration pack to the top of the backpack with existing straps.	• Hydration pack (level ground location)
MOLLE Enclosure (short term proposal)	Design an add-on set of MOLLE covers for the top and bottom of the existing backpack. Avoid vents and numbers. Match the color of the existing backpack.	• Allow space for lightweight, large volume gear, such as drones, kite cameras, foldable structures, and antennas.
Advanced MOLLE backpack (Long term proposal)	When replacement covers are made for backpacks, incorporate same color MOLLE straps around the top and bottom sides and back, avoiding middle fans (sides) and numbers (back).	• Same as basic MOLLE enclosure above, but with larger load limits.

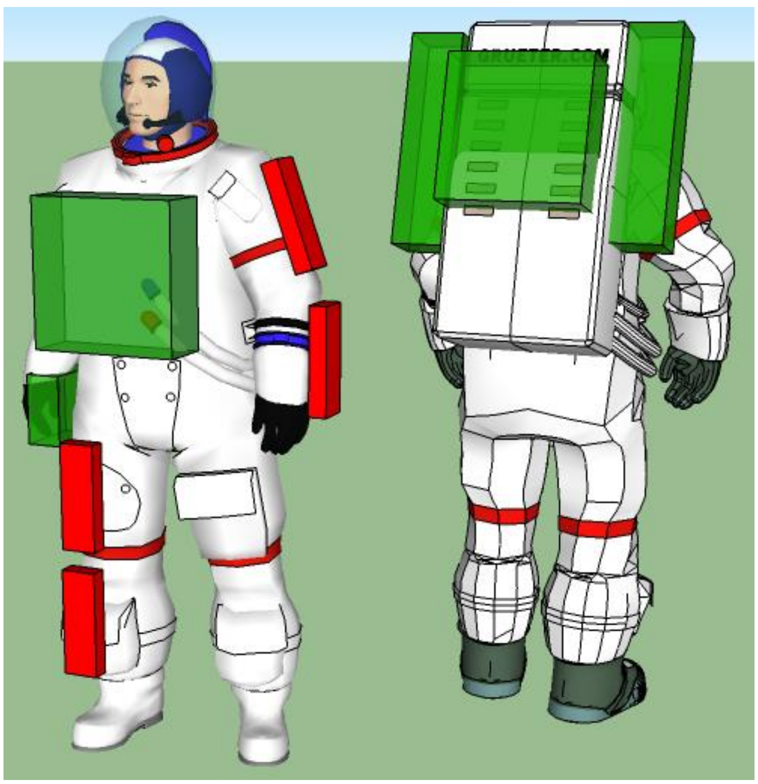

Figure 1: Spacesuit Load Options, Location & Volume

	Accessibility	Visiblity	Load Limit (g)	CG	Height	Width	Depth	Volume	Recommended Gear
Forearms	8	10	250	2	20	8	2	30	Small electronics, mirrors
Upper Arms	2	2	500	6	20	8	2	30	Monitoring/radio gear
Shin	8	5	250	5	20	8	2	30	Samples
Upper Leg	10	4	500	7	20	8	2	30	Mid-range tools, first aid
Hip/Belt	10	4	6,000	10	30	15	8	53	heavy tools, cameras
Backpack (Top)	0	0	1,000	2	10	10	40	60	Light gear, radio gear
Backpack (Sides)	0	0	2,000	5	10	10	60	80	Collapsible gear
Backpack (Back)	0	0	1,000	3	10	10	60	80	Drone, flat equipment
Backpack (Bottom)	0	0	3,000	7	10	15	40	65	Heavy equipment
Chest	9	8	10,000	9	50	30	10	90	Hydration, most field gear

Figure 2: Graph/Table of Load Locations. Longer bars are better.

The Backpack Hatch Suit

Figure 3: NASA Analog Backpack-Hatch Suit

While the MDRS suit was based on the Apollo lunar EVA suit, this concept has been largely replaced by the concept of a suit where the backpack opens like a door. This was originally used on Russian Orlan suit design, which is currently used on Russian EVAs at ISS. This is ideal in the sense that the components in the backpack can be accessed for maintenance with minimal effort once the suit is inside. The Project Constellation Lunar and Martian suit was designed in this way as well, with the intention to leave the suit outside a small hatch and let the crew enter and exit via the backpack door. This dramatically reduces the dust that would enter the small rover cabin.

For MDRS, a backpack-door analog suit would be a substantial effort. The Orlan suit has the advantage or being used in orbit, so that shoulder loads on the crew member would be a non-issue. Analog backpack-door suits used by NASA for Desert Rats and other studies have a large budget and a hard-shell torso piece. A real spacesuit would have the advantage of pressurization and a hard torso shell, so that shoulder straps are not an issue and the door can be fixed to a solid frame.

Beginning Design of an 80:20 Rule Analog Hard Shell Suit

With many high-end designs, a cheaper version can achieve 80 percent of the results for 20 percent of the cost. Where the following design concept falls on that cost to performance spectrum remains to be seen. It is an attempt to start the design conversation on an advanced, low budget analog suit.

This arrangement allows for an advanced version, where a hard shell (cut plastic sheets or fiberglass) can be snapped inside the jacket. This can be hinged with a new backpack. Given the cost of this arrangement and limited utility, it would be limited to specific studies. Since the "hard shell" is not visible to photographers, it could be made in sections and locked in different sizes to expand the shoulders and waist. The shoulders would have to be heavily padded.

After considering this, it was realized that an off-the-shelf motocross chest protector shell could be modified to dramatically simplify development and reduce cost. It would also offer proven ergonomics and enhance safety on ATVs. One model that could be modified, the Thor Adult Quadrant Chest Protector, was found on Amazon.com for $52. The open collar would allow for both shoulder-mounted and head-mounted helmet configurations.

Since the backpack would be clipped into the back of the chest protector, the unit would replace the backpack straps. An optional chest pack could also be integrated. The chest protector could be fitted inside or outside the coverall jacket, and ideally could be configured either way depending on the mission.

Begin with the End in Mind: Incremental to Advanced MDRS Analog Suit Options

The goal of the following study, then, is to break down what in ideal analog suit would be like for MDRS and other analog locations, assuming we want to maximize fidelity and adaptability while keeping the cost reasonable. Options are rated and sorted by estimated difficulty (hours of work and expense of parts).

Element	Diff: 1-10	Improvement Proposed
MOLLE Gear Packs	1	• With MOLLE gear, select "shopping list" of good suit gear options matched to field gear. For example, hot-link to online source for given pouches that are known to fit common field gear (rock hammer, sample containers, etc.) and field-appropriate colors (tan to avoid paramilitary look in photos).
Coverall w/ Gear Straps	2	• Sew MOLLE strips into the abdomen of the suit, forearms, shoulders, and legs where appropriate. Straps will match suit color to minimize appearance when not in use.
Backpack Modified	2	• Add USB charger (probably with separate battery) to the backpack, with plug to keep dust out when not in use. • Add MOLLE straps to top, upper sides, and lower sides for light gear.
Radio/Data Upgrades	3-8	• The radio equipment may be replaced with a cell phone or iPod Touch equivalent app that allows wi-fi point-to-point conference call communications for EVA. Repeaters could be places along routes where

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		appropriate, and extended range wi-fi stations placed on hill-tops near the hab. In emergencies, it may allow cellular internet calls to the hab or local mission support. • It could also allow geotagging of radio communications and photos in a contiguous app, if such an app were developed.
Helmet Option 1 (ATV)	4	• Select a stock motorcycle helmet that roughly matches the design of a space helmet. • Do modifications to cosmetically and if possible mechanically (with faceplate) to simulate a spacesuit helmet.
Chest Protector	5-7	• A motorcycle chest protector is modified to allow it to replace the hardshell of the backpack entry suit. The major difference is that it will be much easier to construct so that the door opens up to the base of the neck than off to the side as in the NASA concept. The backpack is mounted directly on the chest protector to distribute the weight across the upper body.
Integrated Backpack	5-7	• New backpack design integrated with chest protector.
Helmet Option 2 (Integrated)	8	• Custom sculpt helmet to work with backpack entry suit. • If used, give more advanced impact protection than the helmet currently in use with thin layers of high density foam around the inside of the helmet. Leave room for headsets, eye displays, and so on. •
Two-Piece Heavy Suit	8	• Replace the jumpsuit with a separate pants and jacket sections. • Pants would have wear-resistant fronts or at least knees, and possibly built-in attachment points for boot covers. • The jacket would have internal belt loops that would be opposite the belt loops on the pants, allowing a belt to bond the top and bottom sections for the duration of the rotation. This will help the suit fit better and adapt to more body types. It will also allow replacement of worn sections without replacing the whole suit. The neck would accommodate a helmet. • The jacket would have a pair of back zippers from neck to belt on either side, allowing the back to be a single flat sheet (for an external backpack) or a large box-shaped cover for an internal backpack. The zippers would allow for backpack entry without excessive complexity. The backpack pouch would have a removable fabric screen over the fan intake.

Proposed Development Arc for MDRS Suit Design

The proposal below would allow slow migration to this design, with stopping points determined by budget and law of diminishing returns. The progress could be picked up in the next suit design or at another analog habitat in the future, and modified based on lessons learned at that time.

Version	Description	Capability Benefits
2.1 – MOLLE Test	• Use existing suit with MOLLE vest and leg guards.	• Allows crew to experiment with different MOLLE pouches, equipment, and loads. • Determine where gear can and cannot be comfortably carried with existing gear. • Determine what off the shelf MOLLE vest/belt/leg arrangements could be added to MDRS inventory.
2.5 – MOLLE Add-ons	• Make custom MOLLE harness over the existing MDRS backpack cover. • Purchase MOLLE vest/belt/leg arrangements for permanent MDRS inventory. • Add a USB charger port and battery link to the backpack.	• Recommend purchase options for gear pockets to match common gear (sample containers, etc.) • Allows crews to bring pockets and comfortably carry more gear with more protection more ergonomically than currently possible. • Allow recharging of tablets, micro-drones, etc. in the field
3.0 – Modern Modular Analog Suit	• Create custom jacket/backpack combination to emulate backpack entry suits. • Integrated MOLLE straps where appropriate. • Stress points could be made with reinforced material to maximize field service life. • Consider a Kickstarter or equivalent project to fund this phase, with the suit instructions open source for other researchers to modify and advance.	• Advanced suit much more closely resembles planned spacesuit designs. • Hard points allow for carrying of more gear and easier maintenance. • Better ATV safety. • Helmet is more economically mounted. May still be swapped with motorcycle helmet as needed. • Make design open source so that future crews can bring modifications, plug-in modules, etc. and continue the development of the suit design.

Epilogue: MDRS Crew 200

The commander approached the base of Phobos Peak at mid-day to avoid the sun interfering with the experiment.

“OK, unpacking the drone now.”

His XO removed a folded quad-copter from a cylinder on the side of his backpack, unplugged the power line, and unfolded it. Meanwhile, the commander launched a control app on his arm-mounted smartphone. Helmet-mounted cameras recorded the process. The drone was switched on and flew under his control up the side of the hill while he recorded strata and altitude on his smart phone interface. As it crossed the peak, he switched to a downward facing camera on the display to guide it in for a landing. Once down, he aimed the forward-facing camera and communications payload at the hab. After over a decade of crews waking to the view of Phobos Peak, the peak was finally looking back.

“EVA to Hab… The drone is in position. Are you ready to receive?”

“Hab to EVA… Confirmed drone landed. Ready on this end. That was fun to watch in the telescope.”

“Ready transmission.”

A small green laser attached to the camera beamed a pre-recorded bit pattern at low bandwidth to a small telescope and LCD imager at the hab. The software was calibrated to start receiving data on that pixel. It was limited to the refresh speed of the imager to about a three characters per second, so it was a simple text message. Just enough to show the experiment worked.

The computer display showed a green flicker, and the communications window slowly filled in…

`atson, come here.  I want you.`

“We lost the first character, but the rest came in just fine. Congrats! Do you want to try again?”

“EVA to Hab… No, it’s too gusty. I don’t want to make an unscheduled take-off. Let me just get some HD footage of the peak and get the drone back. That will help with the solar-powered relay project they have planned for up there.”

“I just realized – if we can get it up there with a big quad-copter, can’t someone else steal it with one?”

“Not likely. It has a ballast bag that absorbs and retains rainwater over time. It may weigh 5 kilos when we install it, but it will weigh 20 after a good rain. It should also keep it from being blown off the peak.