

Laundry Study for a Lunar Outpost

Michael K. Ewert
Johnson Space Center/NASA

Frank F. Jeng
Barrios Technology/ESCG

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ABSTRACT

In support of the Constellation Program, NASA conducted an analysis of crew clothing and laundry options. Disposable clothing is currently used in human space missions. However, the new mission duration, goals, launch penalties and habitat environments may lead to a different conclusion.

Mass and volume for disposable clothing are major penalties in long-duration human missions. Equivalent System Mass (ESM) of crew clothing and hygiene towels was estimated at about 11% of total life support system ESM for a 4-crew, 10-year Lunar Outpost mission. Ways to lessen this penalty include: reduce clothing supply mass through using clothes made of advanced fabrics, reduce daily usage rate by extending wear duration and employing a laundry with reusable clothing.

Lunar habitat atmosphere pressure and therefore oxygen volume percentage will be different from Space Station or Shuttle. Thus flammability of clothing must be revisited. This paper summarizes recent research efforts in advanced clothing, proposed clothing supply rates, results of a trade-off study between disposable clothing and laundry, and suggestions for Constellation Program clothing.

INTRODUCTION

In support of the Constellation Program for returning humans to the lunar surface and establishing a lunar outpost and beyond, NASA conducted an analysis on crew clothing and laundry options.

Crew garments in space missions include intravehicular clothes, ExtraVehicular Activity (EVA) spacesuits, crew escape suits and associated undergarments. This study focused on intravehicular and EVA clothing that will have to be changed/disposed of in longer duration missions.

Disposable clothing has been used since Apollo until current Space Shuttle and International Space Station (ISS) missions. It was justified that disposable clothing should be used for these generally short missions. However, as Constellation missions will last ten years, and each individual Outpost mission is expected to last 180 days, mission goals, designs and launch penalties for mass and volume are different. For example, the habitat atmosphere pressure (7) and therefore oxygen volume percentage will be different from ISS or Shuttle. Almost daily EVA sorties will be a norm during Outpost exploration missions. All of these factors will have impacts on selection of crew clothing and laundry options for Outpost missions.

Mass and volume estimates for disposable crew clothing have been shown as a major penalty in long-duration manned space exploration missions in previous analyses (25). Assuming disposable clothing as those used on ISS, Equivalent System Mass (ESM) of crew clothing and hygiene towels was estimated to be 11,000 kg, which is about 11% of the ESM of all life support systems for a 4-crew, 10-year Lunar Outpost mission based on Advanced Life Support System Analysis Tool (ALSSAT) results. The entire life support system ESM, which is a measure of all life support hardware and supplies launched plus mass penalties for volume, power and crew time requirements, was estimated to be 97,000 kg for the 10-yr mission.

PURPOSE OF THE STUDY

To achieve the goals of reducing ESM or launch mass, the Constellation Program needs to define its clothing requirements early in the program.

Clothing requirements drive requirements for other systems, including Water, Waste, Habitation, and Air systems. Laundry wastewater is a significant portion of total wastewater loads, and whether it is integrated into a single water recovery system or a standalone system will impact water recovery system designs. Due to its mass and volume, disposal of spent clothes and towels will impact waste systems. Spent clothing and towels have been considered as one possible radiation protection material in the crew habitat. Moisture recovery from worn clothes and towels or dryer effluent, and heat removal from the dryer effluent stream impact air system designs.

Because of the unique gravity environment, mission requirements and infrastructure on the lunar surface, sufficient lead time is required for clothing technology development.

RECENT LAUNDRY AND CLOTHING STUDIES

Perka (19) traded combinations of Exploration Life Support (ELS) technologies, including with and without a laundry capability, for Lunar Outpost missions. Drysdale (4,5,6) addressed clothing issues experienced in Shuttle and ISS missions, suggested clothes options for advanced clothing, and described washer and dryer technologies and break-even implications. Orndoff (16) discussed clothing issues in advanced lunar missions and advanced fabrics for advanced missions. Yeh and Conger (27) included a laundry in the Lunar Outpost baseline technologies in Lunar Mission Parametric Studies. Jeng and Ewert (9) traded laundry versus disposable clothing for long duration missions.

Breakeven times between using disposable clothing and laundry/reusable clothing from recent studies are shown in Table 1.

Table 1. Recent Break-Even Studies and Their Major Parameters

Study	Missions	Crew No.	Author	Disposable Clothing Supply Rate, kg/CM ^c -day	WRS Technologies used in the study	Break-Even Time ^{a,b} , days	Report Year
"Lunar Outpost Technologies Break-Even Study"	Lunar Outpost	4	Perka A. (19)	0.486	VPCAR w/out AES PMWC-Lyoph Storage	144 - 851	2007
"Clothing for Lunar Outpost"	Lunar Outpost	4	Drysdale A.(5)	0.625	Closed water processing system	24 - 81	2006
"Trade Study on Laundry Systems for Advanced and ISS Missions"	Mars	6	Jeng F., and Ewert M.(9)	0.486	Biological Water Recovery System.	145 - 290	2002

Notes:

a) Break-even time varies depending on missions and technology combinations.

b) Break-even time between using disposable clothes and using reusable clothes and a laundry.

c) CM: Crew Member

DISCUSSION OF CLOTHING AND LAUNDRY

ISSUES AND APPROACHES IN OUTPOST CREW CLOTHING

Unique environments and mission requirements in Lunar Outpost missions which impact clothing provisioning include the following:

- Proposed atmosphere pressure and oxygen percentage for Lunar Habitat (7)
- Frequent EVA sorties (7)
- Gravity on lunar surface
- Dust on lunar surface

Crew-Clothes-and-Use-Schedule - Based on ISS practice, crew clothes, hygiene towels, and their use schedules are shown in Table 2. This table shows a clothing daily supply rate of 0.496 kg/CM-d.

Table 2. Current ISS Crew Clothes, Hygiene Towels and Other Provisions (23)

Item	Composition	Use Rate, days	Laundry rate ^{a,b} , kg/CM-day
Sleep Shirt	100% cotton	3	0.0517
Boxer Shorts/Briefs	50/50 cotton/polyester	2	0.0353
Crew Socks/ Tube Socks	100% cotton	2	0.0425
Polartec® Socks/ Slipper Socks	85/13/2 wool/nylon/spandex+leather	30/90	0.0000
Sweater	100% cotton	1 per mission	0.0000
Flight Jacket	100% flame retardant cotton, Nomex®	1 per mission	0.0000
Flight Jacket Liner	100% Cotton + Nomex®	1 per mission	0.0000
Flight Trousers (one pair)	100% flame retardant cotton	10	0.0375
Athletic Shorts	100% nylon, COOLMAX®, elastic waist	3	0.0030
Athletic Support	Cotton, spandex	7	0.0071
Handkerchief	100% cotton	3.5	0.0057
Polo Shirt	100% cotton	10	0.0415
Athletic Headband	Cotton, spandex	30	0.0015
Cycling Shoes	N/A	1 per mission	0.0000
Athletic Shoes	N/A	1 per mission	0.0000
Flight name tag	Velcroed® patch	1 per mission	0.0000
Wet washcloths	Cloths for hygiene wet wash		0.0153
Hygiene Towel, Washcloths, Lintless Towels ^c	Washcloth is used for personal hygiene cleansing. Lintless towels are used for drying body, wiping hands, etc.	0.71	0.245
Sleeping Bag Insert	cotton	30	0.010
Total			0.496

Notes:

a) This is a laundry rate, i.e., dirty clothes and towel accumulation rate.

b) Items which last 90+ days were assumed to last a whole mission and are not summed up in daily clothing supply rate. No washing is considered necessary.

c) 1.4 hygiene towels, including washcloth and lint-less, are projected per crew member per day.

Drysdale (4) has identified potential clothing issues for advanced missions. Those relevant to Lunar Outpost missions are outlined in this section.

Crew clothing should provide appropriate safety and protection besides comfortable covering. Provision of comfortable outfits and safe protection in an elevated oxygen environment is a necessity. Launch penalties for mass and volume of disposable clothing in long duration Constellation missions are also a major concern.

Hygiene-Towel-Laundry-Load-Is-Significant - Table 2 shows that the daily laundry load of the hygiene towels, including washcloths and lint-less towels, is 50+ % of the total clothing (laundry) load. An obvious method to reduce daily clothing supply rate is to reuse the towels and to reduce the hygiene towel supply rate. By reusing hygiene towels alone, the daily clothing and towel supply rate can be cut by almost one half. Other benefits from reusing towels include:

- Recovering moisture from towels, increasing closure of water recovery system
- Improving sanitation problems with wet towels.

Provisions for a dryer are suggested for the Outpost even before a full washer and dryer decision is made.

Fire-Safety-Concerns-of-Clothes-and-Towels - To achieve the goals of the Constellation human space exploration program, the habitat atmosphere pressure and oxygen partial pressure have been set to facilitate extravehicular activities. The lunar reference mission document (7,12) indicates O₂ concentrations of lunar exploration vehicles atmospheres as follows:

Lander	34%
Outpost	36%

Most crew clothing and hygiene towels so far are certified for up to 30% oxygen in a 70.3 kPa (10.2 psia) atmosphere. Whether or not the existing clothing and

hygiene towels can pass flammability certification tests in a 36% oxygen environment is a concern. Testing of crew clothing, hygiene towels and other non-metallic surface materials for 36% oxygen environment is needed.

The current Clothing Materials and Processes guidelines (18) require the following: (1) outer clothing must be fabricated from a material that is nonflammable in 30% oxygen at 70.3 kPa (10.2 psia), (2) underwear, handkerchiefs and other items that are covered by outer clothing may be fabricated from any material, (3) socks may be made from any material.

The above guidelines do not cover the atmospheric pressure and O₂ partial pressure expected in the Outpost Habitat. Tests are suggested to investigate whether these guidelines are still applicable at higher oxygen concentration. Some crew intravehicular clothes, such as the polo shirt (100% cotton), and the athletic shorts (100% nylon), are preferred by the crew and generally are not protected with outer clothing, but they are allowed in limited amount by exception. These should be reviewed in light of higher oxygen levels for Constellation vehicles.

Elimination/Minimization-of-Cloth-Lint-or-Particulates - Both Shuttle and ISS have had problems with airborne debris (4). Debris was caught on avionics equipment screens, occluding airflow and causing failures due to overheating which led to a redesign of the screens. An analysis of debris collected on the Multi-Purpose Logistics Module (MPLM) and Node 1 of ISS clearly indicated that lint dislodged from clothing and towels was a significant component (4) of the debris. With a 1/6 G gravity environment on the lunar surface, the issue of lint on equipment surfaces and the air system will still exist but may be a little better than on Shuttle and ISS.

An approach to minimize lint or particulate generation is using clothes made of advanced fabrics that generate fewer lint particles.

Cleaning-of-EVA-Liquid-Cooling-and-Ventilation-Garment (LCVG) - The LCVG will be worn by the crew hundreds of times for EVA and may possibly be passed from one

mission crew to the next mission in Outpost. The crew's body continuously maintains contact with the inner layer of the LCVG while being worn. Cleaning of the LCVG on the lunar surface may become necessary. With its layered structure and sewing material, replacing or appropriate laundering in a water washer or sanitation treatment is an issue to be investigated.

Impacts-of-Lunar-Dust-on-Clothing - Dust contamination on EVA suits and related problems in Apollo missions had been reported by Apollo astronauts (16). Apollo astronauts took extra efforts in removing lunar dust from their EVA suits and underwear.

While there will be an airlock/equipment lock for interfacing between EVA and IVA operations, and most dust should be removed at the lock, certain clothing modifications could be conducted so that sand/dust adhering could be reduced or eliminated. Vinyl clothing is rather unusual in general life, but a smooth vinyl surface is one idea that has been suggested for the exterior of the EMU, rather than beta cloth as is currently used (4).

Taking-Advantage-of-Advanced-Fabrics - North Carolina State University measured the properties of cotton clothing fabric and other fabric using standard lab tests (4). Results are shown in Table 3.

Table 3. Summary of Fabric Property Test Results (NCSU test data)

Property	Goal	Jockey Cotton	Under Armour	Nike Dri-Fit	Holofiber	Nomex	Medalist X-Static
		A	B	C	D	E	F
Weight (oz/ yd ²)	low	4.88	4.38	3.78	6.89	6.47	5.73
Thickness (mm)	low	1.18	0.82	0.74	1.12	1.08	1.06
Extensibility (%)	high	24.6	23.5	12.9	54.3	18.9	10.3
Vertical Wicking (cm at 10 min.)	high	4.4	13.7	14.8	8.8	10	10.8
Bending Rigidity (mg cm)	low	32.9	12.8	8.8	13.4	14.7	28.5
Thermal Comfort Index (w/m ²)	high	291	315	318	272	279	262
Lint generation, total particles	low	138,000	7,160	7,410	10,000	13,500	51,600
Accelerated washing, appearance	NC	smoother	NC	duller	lint	duller	NC
Accelerated washing, colorfastness	high	5	5	4	5	4.5	4.5
Accelerated washing, staining	high	5	5	4.7	4.7	4.7	2.5 – 5
Bursting, N	high	488	710	646	308	667	787
Pilling rating	high	1	5	5	2	4.75	5
Snagging	high	4.6	2.3	3.1	4.5	4.8	5
Flammability, seconds*	high	11	22	22	20	IBE/DNI	28
Microbial activity assessment	high	NI	NI				NI
% change in length from washing	low	2.4%		1%		1%	
% change in width from washing	low	4.2%		1%		3%	
Weight change from washing	low	5%		0.4-1%		0-4%	

NC – no change. IBE – ignited but extinguished. DNI – did not ignite. NI – no inhibition

* Flammability in near-sea-level terrestrial conditions

Results from this table show that clothing made of many of these advanced fabrics would have lower mass and volume, for example Nike Dri-Fit would have 77% of the mass of cotton fabric and 63% of the volume of cotton. The lint generation of advanced fabrics will be much less than clothing made of cotton. Advanced fabrics generally are more thermally comfortable. In addition, all of the advanced fabrics in Table 3 have less flammability risk than traditional fabrics.

Polybenzimidazole (PBI), which is a flame resistant clothing fiber, is used in some advanced clothing fabrics that are thermally comfortable. The Limiting Oxygen Index (LOI) of PBI is reported to be 38 – 58% (17, 22).

T-shirts made of PBI were worn and evaluated by Skylab astronauts. Some of the astronauts' comments were as follows: "Shirt made of PBI was not as comfortable as T-shirt made of cotton." "When it was worn just over skin, it would get dirty quicker and get smelly." "It didn't absorb moisture" (24).

In the future Outpost missions, acceptance testing of advanced clothing fabric will need to be conducted. Safety and comfort will have to be weighed during these evaluations.

Extension-of-Clothes-Change-Schedule - It is possible that the change schedule of clothes and towels can be readily doubled through using advanced fabrics. Clothes change schedule could be extended by eliminating microorganisms and odors and by removing moisture in a dryer alone.

LAUNDRY TRADE STUDY

Crew-Clothing-Supply-Rate-in-Review - A summary of relevant crew clothing supply rates from different sources, in kg/CM-d, follows:

Actual average crew clothes supply (ISS EXP 9 – 13)	0.137
Standard deviation -	0.064
Hygiene towels are not included.	
Estimated hygiene towel, washcloths	<u>0.245</u>
Estimated daily clothes + hygiene towels	0.382
Estimate based on ISS US joint Crew (Table 2)	0.496
Based on Provisioning Catalog, 2003	
Clothes + hygiene towels based on BVAD ^a	0.343
ISS Consumable Team estimate – 2003 ⁷ (no towels)	0.200
CEV clothes and supply estimate, including personal preference items ^b	0.450

Notes:

a) BVAD, Section 5.3.1., NASA/CR-2004-208941

b) Per email from J. Villarreal/EC3/JSC, March 7, 2007.

A disposable crew clothes and hygiene towels supply rate of 0.38 kg/CM-d was used as the baseline supply rate in this analysis.

To get a feeling of a total daily clothes and towels use at 0.38 kg/CM-d, the ISS current clothing usage rate (Table 2) was modified mostly through extending the clothes change schedule. Table 4 is a possible combination of clothes use rates with the total at 0.38 kg/CM-d, basically assuming that wet washcloth, hygiene towel and cloth change schedules remain the same as ISS original schedules, but the change schedule of athletic shorts, handkerchief, preference shirt, sleep shirt etc. are doubled. The table shows that clothing change schedules are already quite extended.