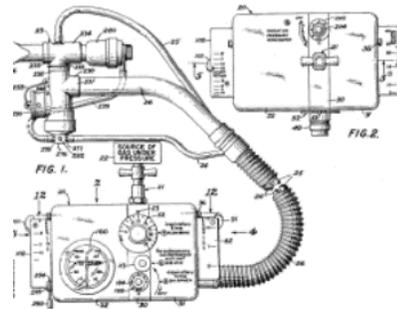


## Anti-g-Garment Development and Testing

### 1) Anti-g-Garment. Introduction and Use in space flights.

A *g-suit*, or *anti-g suit*, is a flight suit worn by pilots and astronauts who are subject to high levels of acceleration force (**g**). It is designed to prevent a black-out and g-LOC (g-induced Loss Of Consciousness) caused by the blood pooling in the lower part of the body when under acceleration, thus depriving the brain of blood. Black-out and g-LOC have caused a number of fatal aircraft accidents.

A g-suit usually has the form of tightly-fitting trousers (see Fig.1), which are worn either under or over the flying suit worn by the crewmembers.



**Fig.1 Anti-g-pants for combat pilots      Fig.2 Regular anti-g-pants valve control box**

The trousers or pants are equipped with inflatable bladders which, when pressurized through a valve box (see Fig.2) in the aircraft or spacecraft, press on the abdomen and legs, thus restricting the draining of blood away from the brain during periods of high acceleration. Military-style, “active” anti-g garments have proven effective in protecting pilots against extreme-g scenarios above 8 Gs. However, these garments are often very heavy, non-breathable and hot, bulky and uncomfortable, and require tanks, valves, hoses and sensors that take up valuable room in today’s commercial vehicles.

Traditional inflated g-pants are limited in use because of their dependence on compressed air and high compression rates. For example, inflation of the Anti Gravity Suit (AGS) during emergency egress from the Space Shuttle limited the crewmember’s capacity to ambulate to a safe distance from the vehicle, by restricting movement in the lower body.

### **Anti-g-pants Centaur**

The Centaur Anti-G Pants are used by astronauts in the Soyuz space ship capsule. Centaur pants (see fig. 3) are worn under the Sokol space suit and used in launch/reentry/landing phases of flight, and after flight. This garment is customizable to the crewmember and their condition.



**Fig.3 Centaur adjustment on astronaut's leg before donning to Sokol space suit.**

Centaur pants are used by astronauts and cosmonauts after space flight for acclimatization to Earth gravity. However, because the knee, calf joints and groin are uncompressed, edema formation in these areas during chronic use is possible and has been reported.

### **FFD's Advanced anti-g technology**

Final Frontier Design (FFD) has developed Advanced Passive Compression G-Pants (APCGP), that do not require a compressed gas source like ordinary anti-g-pants. APCGP's design is a non-inflatable garment that consists of elastic, laced pants. APCGP can be adjusted for optimal fit and comfort without additional hardware requirements. APCGP is much easier for donning, doffing, and cabin integration, in comparison to traditional anti-g-pants. It can be worn under flight outfits or inside space suit.



**Fig.4 APCGP by Final Frontier Design**

Passive compression of FFD's garments ranges from 20-40 mmHg along the flesh. These compression rates are high enough to provide increased upper body blood pressure, and are low enough to be worn for extended periods without serious risk. In addition, the garments are breathable and lightweight, providing cooling along the body because of a slight decrease in blood flow. This is in contrast to active g-garments, which contain airtight bladders and can be hot and restrictive.

**Comparative analyses of anti-g-technologies: Table 1**

#	Properties	Inflatable G-Pants	Soyuz G Pants	APCGP by FFD
1	Weight, pounds	6 pounds	2 pounds	3 pounds
2	Valve control Box	Required	Not required	Not required
3	Acclimatization to normal gravity	No	Yes	Yes
4	Knee joint's protection	No	No	Yes
5	Hip areas protection	No	Yes	Yes
6	High waist and back support	No	No	Yes
7	Feet protection or g-socks	No	No	Yes
8	Compression Rate	78 mmHg (1)	30 mmHg (1)	20-40 mmHg

## 2. Anti-g-Garment Testing

FFD conducted comparative testing of anti-g-garments in their laboratory using an undergarment fitted with pressure sensors. FFD has verified passive, graded compression rates from the feet to the high waist, and tested for critical biomedical statistics.

APCGP is constructed of a high strength stretch fabrics, carefully placed closures, and extensive lacing to ensure good sizing and adjustable pressures for various body types. Compression rates are graded from highest at the feet to lowest along the thighs, with reinforced fabric at compressed areas. The bony areas of the knees are not reinforced, offering lower pressures but providing comfortable flexibility and protection from edema along compression-edge zones. Zipper closures at the foot and ankle, and Velcro on calf and waist provide easy donning and doffing and additional adjusting.

### OBJECTS TESTED

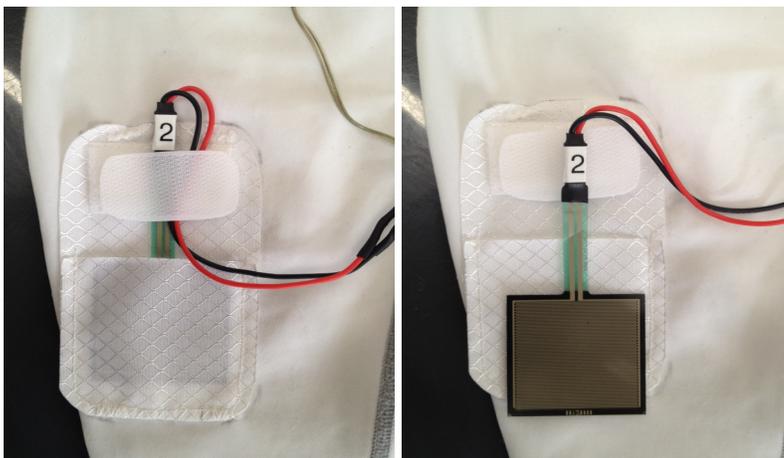
- 1) G-Pants #4 of FFD development, size XL
- 2) G-Socks #3 of FFD development, size 11
- 3) Medical compression socks 30-40mmHg
- 4) Medical compression socks 15-20mmHg



**Figure 5. FFD G-Pants and G-Socks: Side (Left) and Front**

## METHODS

In order to test and verify the compression of FFD's anti-g garments, we have developed undergarments with "Force Sensing Resistor" (FSR) sensors, built into pockets along strategic locations under the garments. Worn under compressive garments, these FSRs provide raw force data about the relative compression against the body. The sensors are run through a simple resistive circuit and a microcontroller, which outputs raw serial data to a computer.

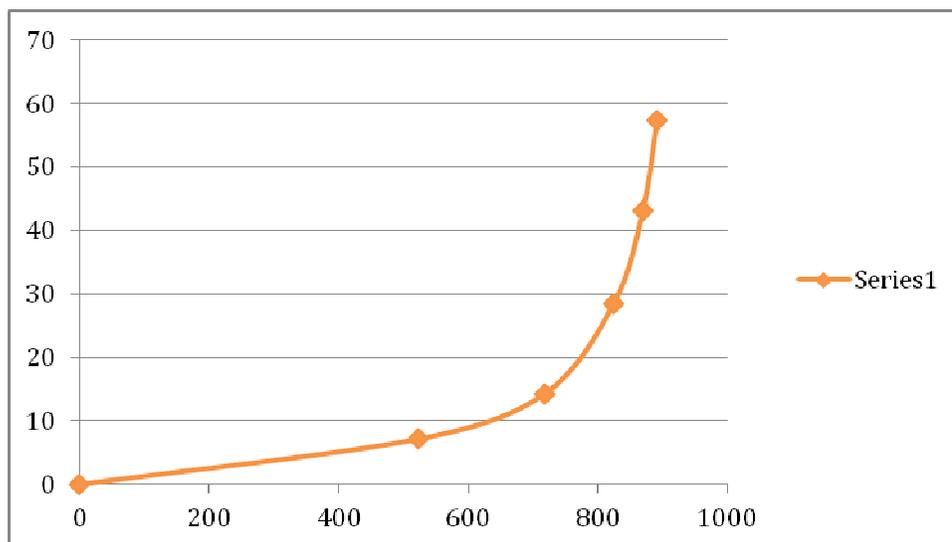


**Figure 6. FSR Sensor, 1.5" X 1.5" Shown in the Pocket (Left) and out of Pocket (Right)**



**Figure 7. FFD's FSR Underwear**

The FSR sensors were first calibrated using a force handheld force sensor. Using a solid plastic block 2.25" square, a force sensor was used to apply a range of constant forces to 3 separate sensors, with 15 measurements taken for 5 force ranges for each of 3 sensors. Raw serial data was logged on the computer, given the input forces. The resultant data was then averaged and a chart was plotted to show the relationship between raw serial data and actual force and pressure. (Figure 8)

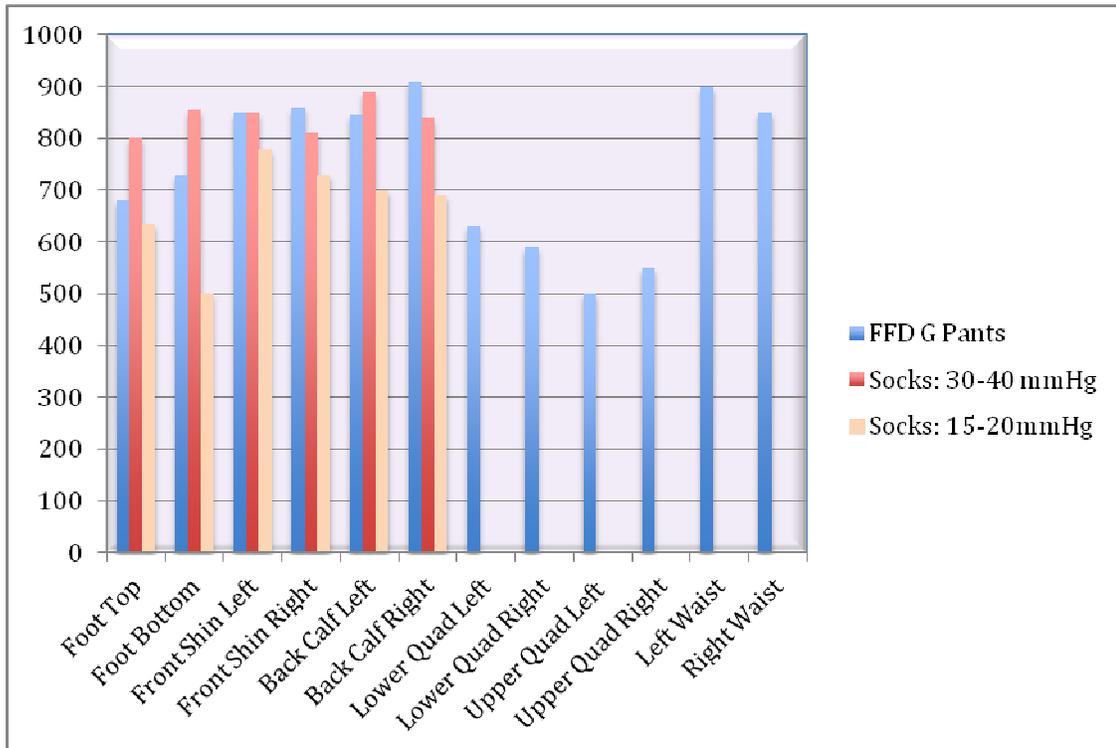


**Figure 8. Calibration Chart, showing mmHg vertically and raw serial data horizontally.**

FFD has compared the compression of various medical grade compressive socks with their passive g-pants, to corroborate data. Measurements were taken in the seated position. Measurements were taken twice, on separate days, to average out the data, and FSR sensors were placed over a total of 12 positions on the lower body.

In addition, blood pressure and pulse of test subject were measured before, during and after the wearing of g-pants using a medical blood pressure monitor. Surface body temperature was measured using a hand held infrared thermometer.

The FSR data gathered (Figure 9) shows that FFD's G Pants compress the legs comparable to a 30-40mmHg medical grade compression sock. This compression rate is similar to that of the Russian Kentvar/Centaur Anti-G garment. Comparing to the calibration chart, it can be seen that the medical grade compression socks provide approximately the level of compression advertised.



**Figure 9. Compression Chart, showing medical socks and FFD G Pants in 12 locations on the legs, vs. Raw Serial Data.**

It should be noted that FFD's G Pants have a great deal of adjustability in the lacing, and compression rates can be changed according to user requirements. Data shown represents a generally high level of compression for this garment. In addition, it was found that the medical compression socks were difficult to don and doff, especially the 30-40mmHg level, and was uncomfortable at the edge of the garment. Instead of g-socks were very easy and fast to don and doff. Whereas, FFD's G Pants were easier to don and doff, and did not have any discomfort during wearing.

Body temperature, blood pressure, pulse rates of test subject were taken of the tester before during and after the wearing of each of these garments. No significant changes were found in any of these metrics.



**Figure 10. FFD G Pants and G-Socks.**

## **Results of testing / Conclusions**

FFD's compression garments provide measureable compression on the human body, comparable to Russian style anti-g pants, without pain or other ill effects. As result they can provide protection against g-forces and add safety to flights with high g-acceleration. Benefits can also extend to astronauts returning to full gravity after prolonged exposure to microgravity, and even stunt pilots or others exposed to extreme – G situations. FFD's passive design greatly simplifies the mechanics of compression, when compared to active bladder anti-G garments, greatly reducing mass on board the vehicle, and significantly bringing down part count and complexity. Finally the passive design is drastically more affordable than active garments.

## **Bibliography**

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