Imagining what life might be like at the International Space Station, the mind conjures up images of astronauts floating around weightless in zero gravity. But what most of us do not think of are the tremendous challenges they face in combating all of the negative effects zero gravity has on the body, from bone-mass and muscle loss to decreases in cardiovascular ability, as well as vestibular or inner ear/balance issues.

Astronauts are now more vigilant than ever in their physical training and nutrition in preparation for a mission, while in-flight and once they return home to Earth, and recent advances in fitness equipment available for use at the International Space Station are helping Astronauts limit losses incurred during space missions, and getting them back to Earth in better shape than ever before.

“From a weight training and cardio standpoint, the training the astronauts do to prepare for flight and the training they do in-flight helps to mitigate the losses somewhat,” explains Mark Guilliams, National Aeronautics and Space Administration (NASA) Astronaut Strength and Conditioning and Rehab specialist, Johnson Space Center, Texas. Guilliams, who has been working at the Johnson Space Center for nearly 20 years, has seen firsthand the evolution in the fitness equipment used to keep astronauts fit in space.

“We have come leaps and bounds since we first started,” he says. “While we are not completely wiping out muscle and bone loss in-flight, the trend is looking better. And I do believe that the progress we have seen can be attributed to the advances we have made in in-flight hardware and training.”

PREPARING FOR FLIGHT

When preparing astronauts for the rigors of flight, the training regimen is similar to that of athletes preparing for a full season, including a good mix of cardio and weight training, as well as functional exercises.

“From a pre-flight conditioning perspective, we are having them do not only the things that they won’t be able to do in-flight, but also preparing for the specific workouts they will be doing in-flight,” he explains. “The main types of lifts we
focus on are squats and dead lifts, and then auxiliaries and everything that goes with that. We also do bench presses, shoulder presses, bent over rows, pull-ups, push-ups – the gamut of everything that you would do during athletic training. We try to get them in the best shape we can in the time that we have available, and also make sure that they are comfortable doing the in-flight exercises that they will be doing. Once they are in space, we are not going to be there to correct form, or monitor how they are doing exercises.”

Getting astronauts familiar with the in-flight exercises is a challenge, especially working with people who come from such diverse and different backgrounds with differing levels of experience with fitness and strength training.

“You have to remember that the average age for astronauts is mid-40’s, and some of them have never done this kind of stuff in their life,” notes Guilliams. “In some instances we are teaching them how to do squats and dead lifts for the first time. We have Ph.D.s who have never done anything – to guys who played collegiate-level football and are familiar with the training – so we are tweaking what they are doing based on individual need.”

Three to four months out from a launch, Guilliams and his team start focusing a lot more on what astronauts will be doing in-flight, so that it just becomes second nature to them once they get there. “We run the same programs here that they will do in-flight, so they are comfortable with them,” he points out.

The new fitness center at Johnson provides all of the equipment needed to help astronauts prepare for missions in space – and to help them get back into peak shape once they return. At approximately 12,000 square feet, the Johnson fitness center features a 6,000-square-foot weight room area or what astronauts call “the floor,” with state-of-the-art cardio and weight training equipment from Life Fitness, Hammer Strength, Iron Grip, Cybex, Woodway, Quinton, Vision and Concept2.

The weight room area is broken down into four different sections, including a complete free-weight space (the largest area), a selectorized equipment area for circuit training, a cardio area, and an open floor area to do functional training, such as agility drills and plyometrics.
configurations, so there is considerable training that must go on in preparation.”

He points out that aRED was introduced two years ago and is an important evolution to iRED (interim Resistive Exercise Device) – the original resistive device that was used in-flight for many years before aRED was created.

“The iRED used rubber to provide resistance and we could only go up to 300 pounds, which once you remove body weight of the astronaut from that number, it did not provide enough resistance,” Guilliams explains. “The aRED uses a vacuum cylinder that creates a vacuum seal, and we have fly-wheels that provide inertia, so it provides more of a free-weight type of a movement and allows us to go up to 600 pounds.”

He points out that from a resistance standpoint this new technology allows them to do almost everything one can do in the gym.

“The main exercises that we do on aRED are squats and dead lifts, and we break it up based on what we are going to do from an in-flight perspective,” he points out. “What we try to do is vary the amount of load that is being applied to the body as well as try to change the angles in which the muscles are working at. For example, with squats, we will do a regular set of squats on one day, and then on another day we will do a single-leg squat, so it actually brings the foot into the center line with the body, and changes the angle from the foot to the hip. Then, on another day, we will do what we call a sumo squat or wide-stance squat, which brings your feet out really wide, again changing the angle from the feet to the hip. Each day we are attacking muscles in the hip from a different angle and at different intensities. And we take the same approach for the dead lift.”

In total, astronauts do weight and cardio training six days a week for two and a half hours per day.

“We do shoulder and bench presses, bent over rows – we work every single muscle group in the body,” notes Guilliams. “We prescribe their workouts for them everyday, so when they are in orbit, they just turn on the computers and it tells them what their workout is for the day.”

Periodization is an important concept in the overall fitness and conditioning approach at NASA.

IN-FLIGHT FITNESS

The in-flight hardware or equipment available to astronauts has improved greatly over the years and consists of a treadmill named TVIS, which stands for treadmill vibration isolation system; a Combined Operational Load Bearing External Resistance Treadmill (COLBERT) or T2, which is a newer, more evolved version of TVIS; a cycle ergometer vibration isolation system or CEVIS; and an advanced resistive exercise device or aRED.

“We train them here at Johnson on how to use these in-flight pieces of equipment so they are familiar with it when they are at the space station,” notes Guilliams. “Our specialized equipment is a little more complicated than your standard treadmill or cycle. For example, aRED can do so many exercises using many different
“If you look at periodization in terms of working with an athlete, for example, you are going to do a straight, linear periodization, including workouts starting with 12 reps, then 8, then 6 and then 4. You are preparing them so you are decreasing the amount of volume that they are doing but you are increasing the intensity at which they are doing it. With iRED, though, we couldn’t do that because they were maxing out the weight we could provide them.

“Now, with aRED we can do a much more traditional type of program, and we can vary the exercises and load within a given week, so we are doing more of an undulating periodization. So, for example, on Monday we will do reps of 6 with heavy weight, on Tuesday we’ll do 12, on Wednesday 8, and then on Thursday we will do 6 again with heavy weight. We also rotate the actual exercises they are doing, so it differs each day, and they may do a short set of squats with heavy weight one day and then the next short set of heavy weight will be done as a dead lift. We also change the stances, the angles and the intensity. The idea is to trick the body and avoid plateaus.”

RESISTANCE IN ZERO G

The greatest challenge for Guilliams and his team is combating zero gravity and factoring body weight into the overall equation.

“From a resistance standpoint on the aRED, when you look at doing squats or heel raises, you have to add back body weight, because in a zero-gravity environment there is no body weight,” he explains. “We add 75 percent of their body weight back into the equation, so if they are doing 200 pounds for 10 reps for a squat and they weigh 100 pounds, in-flight they would be doing 275, not 200. We make up for the zero gravity by adding body weight exercises into the mix.”

For the treadmill astronauts use a harness, and are held down by bungee cords, which also provide some load. T2, which is the newer version of the original treadmill called TVIS, is the product of collaboration between NASA and Woodway.

“The new treadmill is really nice and we are looking into some different loading systems for the treadmill,” notes Guilliams. “We would like to try and experiment in-flight with doing high-velocity Olympic lift-type of movements. Right now we have to work within a certain frequency because there are some issues relating to how the forces that are applied into the machine get applied into the space station. So there are a number of factors that you’ve got to take
into account when you are doing certain exercises.”

NASA has made huge advancements in physical-training options available to astronauts in-flight, and the new equipment has more capabilities and the freedom to do many exercises on one machine.

“We developed TVIS and iRED, which evolved into T2 and aRED, which were great advances, and allow us to do so much more now than we were able to do in the past,” says Guilliams. “For example, the 300-pound maximum was a big limitation with the iRED, especially when you are looking at providing enough resistance for a 200-pound man. Another limitation was using iRED’s elastic (rubber) component, which makes it harder as you stand up and easier as you move down. So, the rubber gives you an ascending-force velocity curve instead of a descending-force velocity curve. But with the aRED, we use a vacuum as opposed to the rubber, which provides not only 600 pounds of force, but a normal-force velocity curve that makes it feel like you have a bar on your back when you do a squat or a dead lift. Because of the aRED we can do much more of a traditional workout program for them than what we did with the first device.”

Even with all of the new advances, the biggest focus and concern is still combating bone-mass and muscle loss.

“The average bone-mass loss is about one percent per month,” notes Guilliams. “But astronauts differ in how much they are affected because of differences in physiology, bone mass and muscle structure, how they adapt to the environment, and how vigilant they are with their training. The main things that we deal with when they get back are neuro-vestibular or balance issues. We see inner-ear issues, which effect balance and coordination, as well as losses in cardio capabilities, muscle strength, power and endurance.”

**POST-FLIGHT FITNESS**

Once astronauts return home from space, it is imperative that they begin their post-flight conditioning and rehabilitation immediately.

“We start our post-flight reconditioning at R-plus one, which means the day after they return home,” Guilliams explains. “We start them weight training on day one, including some form of cardio every day, as well as agility and coordination exercises and drills. We start out on the cycle and move to an elliptical, and then go to a treadmill and then around week three or four we will go outside and start running.”

In addition to the traditional cardio and weight training, functional training allows astronauts to incorporate exercises that help them to regain their equilibrium, which can be thrown off by spending so much time in zero gravity.

“The functional, plyometric exercises are sorely missing in-flight, and this is where we will begin to work on power, agility and footwork using running ladders, cone drills, ply-boxes – all of the exercises that you would normally see athletes doing,” notes Guilliams. “From a vestibular standpoint, we try to incorporate balance training into everything that we do. We do a dynamic warm-up every day, including head and trunk movements in every direction. We are doing it to warm up the body but small head movements after space travel can be very provocative. If you had an inner-ear issue, it can be a challenge but if they are working through it during the warm-up and during the exercises, it begins to work itself out and they start to return to normal gradually, over time.

“Even when we are doing medicine-ball exercises, we incorporate many positions and throws that require balance and head movement and control, which helps them to work through these issues without focusing on the issues specifically. We continue for 45 days after flight and progress in difficulty and variety throughout that period of time and beyond.”

Other important resources are the on-site laboratories, which focus on the research side of things. Post-flight testing at the lab helps trainers to pinpoint weaknesses and deficiencies that need improving.

“The exercise lab does pre-flight, in-flight and post-flight testing,” notes Guilliams. “The exercise lab does VO2 and isokinetic testing and is looking at single joint and single muscle movement – the quad and hamstring, for example. The Neurological group also does a lot of the more provocative type of balance and neurological testing from the inner-ear standpoint. In coordination with the exercise lab we develop aerobic workouts and protocols that we want them to do in flight to try and maintain their VO2. It allows us to know what kind of workload that they need to be working out at.”

Although the lab has specialized equipment to do an array of post-flight testing, Guilliams says he can tell immediately what each astronaut needs by just looking at them.

“I have been doing this long enough to know what type of shape they are in by the way they look and are moving,” he says. “I know when they get back from a mission what they will need to get back into peak shape.”

Because of the new advancements in equipment and a renewed commitment from astronauts, Guilliams is now seeing astronauts returning in better shape from missions than they did in the past.

“The perspective on fitness has changed,” notes Guilliams. “We have high participation in the training programs and everyone sees the benefit of them. The program has come a long way since I started here. Astronauts are floating around for most of the day, which is like laying in bed, and it is so hard to make up a 24-hour period in 2-1/2 hours a day that they use to exercise. But we have made progress and we are starting to fine-tune what we are doing in-flight. I don’t know if we’ll ever get to the point where there is zero bone or muscle loss, but that is our goal.”

—GRAF