

Presented -

28 Aug 74

S.L. Symp.

*~~Mon~~
Tues ✓*

MUSCLE DECONDITIONING

A MAJOR PORTION OF MAN'S MUSCULO-SKELETAL SYSTEM IS DEDICATED TO SUPPORTING AND MOVING HIS BODY AGAINST EARTH'S GRAVITY. THIS MASS OF MUSCLE PLACES HEAVY REQUIREMENTS FOR SUPPORT ON OTHER BODY SYSTEMS. FOR EXAMPLE, MAXIMUM CAPACITY OF THE CARDIOVASCULAR AND RESPIRATORY SYSTEMS, AND TO A LARGE MEASURE THEIR CONDITION, IS A FUNCTION OF DEMANDS FROM THE BODY'S MUSCULATURE. IT IS A COMMON EXPERIENCE THAT REMOVAL OF MUSCLE STRESSES UNDER 1-G, THAT IS, LACK OF SUITABLE EXERCISE, RESULTS IN ATROPHY OF BOTH MUSCLE AND ITS SUPPORTING SYSTEMS. IT COULD BE CONFIDENTLY PREDICTED THAT ATROPHY WOULD OCCUR RAPIDLY UNDER WEIGHTLESSNESS UNLESS SUITABLE EXERCISE WAS PROVIDED.

(THE TIME TAKEN FOR SUCH)

MUSCLE - 2

THE TIME TAKEN FOR SUCH ATROPHY TO OCCUR ALLOWED
SHORT MISSIONS SUCH AS APOLLO TO PROCEED WITHOUT SIGNIFICANT
No Muscle Function evaluations were ^{originally} scheduled on ~~the~~
PROBLEMS. ~~but~~ ^{it} WAS NO LONGER POSSIBLE TO CONSIDER A LONG
but some of ~~it~~ felt-

MISSION LIKE SKYLAB WITHOUT (1) SOME METHOD OF EVALUATING
MUSCLE CONDITION; AND (2) SUITABLE IN-FLIGHT EXERCISE.

ON SKYLAB, WE INSTITUTED FIRST A MINIMUM IMPACT
MUSCLE FUNCTION TEST, AND AS THE MISSION DEMANDED,
ADDED EXERCISE AND EXERCISE DEVICES AND EXPANDED THE
TESTING. THE RESULT WAS A DIFFERENT EXERCISE ENVIRONMENT
ON EACH FLIGHT, SUCH THAT WE HAD THREE EXPERIMENTS,
WITH THE RESULTS OF EACH FLIGHT AFFECTING THE NEXT.

THE FLIGHTS WILL BE DESCRIBED CHRONOLOGICALLY. THIS
REPORT WILL, INsofar AS POSSIBLE, ADDRESS ONLY ~~ASPECTS~~
~~OF~~ SKELETAL MUSCLE SINCE THE CARDIOVASCULAR ASPECTS OF
CONDITIONING AND USE OF THE BICYCLE ERGOMETER ARE
COVERED IN ANOTHER EXPERIMENT.

(EVALUATION OF)

EVALUATION OF THE RIGHT ARM AND LEG WAS DONE PRE - AND POST-FLIGHT ON ALL MISSIONS WITH THE CYBEX ISOKINETIC DYNAMOMETER. THIS DYNAMOMETER MAY BE ROTATED IN EITHER DIRECTION WITHOUT RESISTANCE UNTIL AN ADJUSTABLE LIMIT SPEED IS REACHED. SPEED CANNOT BE INCREASED ABOVE THIS LIMIT BY FORCES OF ANY MAGNITUDE, THAT IS, THE CONSTANT SPEED-MAXIMUM FORCE OF ISOKINESIS IS ACHIEVED. INPUT OR MUSCLE FORCES ARE CONTINUOUSLY RECORDED. VARIOUS ARMS, HANDLES, AND THE LIKE MAY BE ATTACHED TO THE DYNAMOMETER TO COUPLE ANY DESIRED SEGMENT OF THE BODY TO THE MACHINE.

SLIDE 2-1

THE ARRANGEMENT USED ON SKYLAB IS SHOWN HERE. A CREWMAN, AFTER THOROUGH WARM UP, MADE 10 MAXIMUM EFFORT FULL FLEXIONS AND EXTENSIONS OF THE ARM AT THE

(ELBOW AND)

ELBOW AND OF THE HIP AND KNEE AT AN ANGULAR RATE OF
7 1/2° PER SECOND.

SLIDE 2-2

A CONTINUOUS FORCE RECORD WAS MADE OF EACH
REPETITION AT A RATE OF 25 MILLIMETERS PER SECOND AND
THE INTEGRAL OF FORCE, OR UNDER THESE CONDITIONS, WORK
IS RECORDED ON A SECOND CHANNEL.

MACHINE ERRORS ARE SMALL, 2 TO 3 PERCENT OR LESS.
THE TEST GIVES A MEASUREMENT OF STRENGTH COMPARABLE TO
THE MORE COMMONLY USED ISOMETRIC TESTING, BUT HAS THE
GREAT ADVANTAGE OF RECORDING THIS FORCE THROUGHOUT
THE WHOLE RANGE OF MOTION AS WELL AS ALLOWING A NUMBER
OF REPETITIONS FOR STATISTICAL PURPOSES. IT IS SENSITIVE
ENOUGH TO SHOW SMALL CHANGES IN PERFORMANCE WHICH MAY
OCCUR IN DAYS.

(A GREAT DEAL)

SLIDES OFF

A GREAT DEAL OF INFORMATION IS CONTAINED IN THE RECORDINGS MADE, BUT ONLY ONE QUANTITY WILL BE USED HERE -- THE PEAK FORCE OF EACH REPETITION AT THE SAME POINT IN THE CYCLE. USE OF A SINGLE POINT ON THE TENSION CURVE TO REPRESENT THE ENTIRE CURVE MAY BE OPEN TO CRITICISM, ESPECIALLY IN THE LEG WHERE A NUMBER OF MUSCLES ARE INVOLVED. HOWEVER, FOR THE PURPOSES HERE, I FEEL THIS IS A VALID MEASURE OF STRENGTH OF THE MUSCLES TESTED.

SLIDE 2-4

A PLOT OF SUCH PEAK POINTS FROM A PRE-FLIGHT AND POST-FLIGHT CURVE IS SHOWN. THE STRENGTH FOR A GIVEN MOVEMENT IS TAKEN AS THE AVERAGE OF 10 REPETITIONS. AS YOU CAN SEE, A FATIGUE DECREMENT IS PRESENT AND MAY VARY. IT IS INCLUDED IN THE STRENGTH FIGURE BY VIRTUE OF AVERAGING THE 10 REPETITIONS.

SLIDES OFF

(ON SKYLAB 2)

MUSCLE - 6

ON SKYLAB 2 ONLY THE BICYCLE ERGOMETER WAS USED FOR INFLIGHT EXERCISE. PETE CONRAD USED IT IN THE NORMAL FASHION AND WAS THE ONLY PERSON ON SKYLAB TO USE IT IN THE HAND-PEDAL MODE AND ^{WAS} ^E ALSO THE ~~ONLY~~ PERSON ON THIS CREW TO EXERCISE AT RATES COMPARABLE TO THOSE OF LATER MISSIONS.

ON SKYLAB 3, TESTING WAS PERFORMED AT F-18 AND R + 5. IT WAS RECOGNIZED THAT THIS WAS TOO FAR REMOVED FROM THE FLIGHT, BUT WAS THE BEST THAT COULD BE DONE UNDER SCHEDULE CONSTRAINTS.

BY THE TIME MUSCLE TESTING WAS DONE ON DAY 5, THERE HAD BEEN A SIGNIFICANT RECOVERY IN FUNCTION; HOWEVER, A MARKED DECREMENT REMAINED. RESULTS FROM SL-2 WILL BE SHOWN IN A MOMENT IN CONJUNCTION WITH THE RESULTS FROM SKYLAB 3. THE DECREMENT IN LEG EXTENSOR STRENGTH APPROACHED 25 PERCENT, WHILE THE

(ARMS HAD)

ARMS HAD SUFFERED LESS BUT ALSO HAD MARKED LOSSES.

THE COMMANDER'S ARM EXTENSORS HAD NO LOSS, SINCE HE

USED THESE MUSCLES IN HAND- PEDALLING THE BICYCLE. THIS

ILLUSTRATES A CRUCIAL POINT IN MUSCLE CONDITIONING:

TO MAINTAIN THE STRENGTH OF A MUSCLE, IT MUST BE STRESSED

TO OR NEAR THE LEVEL AT WHICH IT WILL HAVE TO FUNCTION.

LEG EXTENSOR MUSCLES WHICH SUPPORT US IN STANDING AND

PROPEL US IN WALKING MUST DEVELOP FORCES OF HUNDREDS-

OF-POUNDS, WHILE THE ARM EXTENSOR FORCES ARE MEASURED

IN TENS-OF-POUNDS. ~~PEAK FORCES DEVELOPED IN PEDALLING~~

THE BICYCLE ERGOMETER EVEN AT 300 WATTS-PER-MINUTE

ARE A FEW TENS-OF-POUNDS, SAY 30-40; AND ARE TOTALLY

INCAPABLE OF MAINTAINING LEG STRENGTH. THE BICYCLE

ERGOMETER IS AN EXCELLENT MACHINE FOR AEROBIC

EXERCISE AND CARDIOVASCULAR CONDITIONING, BUT IT SIMPLY

(CANNOT DEVELOP)

CANNOT DEVELOP EITHER THE TYPE OR LEVEL OF FORCES TO
MAINTAIN STRENGTH FOR WALKING UNDER 1-G.

IMMEDIATELY AFTER SKYLAB 2, WORK WAS STARTED ON
DEVICES TO PROVIDE ADEQUATE EXERCISE TO ARMS, TRUNK, AND
LEGS. A MASS-PRODUCED COMMERCIAL DEVICE, CALLED
MINI GYM, WAS EXTENSIVELY MODIFIED AND DESIGNATED
"MK I". A CENTRIFUGAL BRAKE ARRANGEMENT APPROXIMATED
ISOKINETIC ACTION ON THIS DEVICE.

SLIDE 2-5

ONLY EXERCISES WHICH PRIMARILY BENEFITTED ARMS
AND TRUNK WERE AVAILABLE AS SHOWN HERE. FORCES
TRANSMITTED TO THE LEGS WERE HIGHER THAN THOSE FROM
THE ERGOMETER, BUT THEY WERE STILL LIMITED TO AN
INADEQUATE LEVEL BY THE MAXIMUM STRENGTH OF THE ARMS.

(A SECOND DEVICE,)

MUSCLE - 9

A SECOND DEVICE, DESIGNATED "MK II", CONSISTED OF A PAIR OF HANDLES BETWEEN WHICH UP TO FIVE EXTENSION SPRINGS COULD BE ATTACHED, ALLOWING MAXIMUM FORCES OF 25 POUNDS PER FOOT OF EXTENSION TO BE DEVELOPED.

THESE TWO DEVICES WERE FLOWN ON SKYLAB 3, AND FOOD AND TIME FOR EXERCISE WAS INCREASED IN FLIGHT. THE CREW PERFORMED MANY REPETITIONS PER DAY OF THEIR FAVORITE MANEUVERS ON THE "MK I" AND, TO A LESSER EXTENT, THE "MK II". ALSO, THE AVERAGE AMOUNT OF WORK DONE ON THE BICYCLE ERGOMETER WAS MORE THAN DOUBLED ON SL-3 WITH ALL CREWMEN PARTICIPATING ACTIVELY.

RESULTS OF MUSCLE TESTING OF SL-3 CREWMEN DEMONSTRATED MARKED DIFFERENCES FROM THE SKYLAB 2 CREW.

(LOOKING AT ARMS)

SLIDE 2-6

LOOKING AT ARMS ON SL-3, ONE SEES COMPLETE
PRESERVATION OF EXTENSOR FUNCTION AND ALMOST COMPLETE
PRESERVATION OF FLEXOR FUNCTION IN CONTRAST TO SL-2.
THE SCIENCE PILOT SHOWED A MARKED GAIN IN ARM STRENGTH.
THIS IS THE RESULT OF PUTTING A GOOD DISTANCE RUNNER,
WHICH OWEN IS, ON A WEIGHT-LIFTING PROGRAM.

SLIDE 2-7

LOOKING NOW AT LEG FUNCTION, WE SEE A DIFFERENT
PICTURE. ONLY TWO SKYLAB 3 CREWMEN ARE SHOWN SINCE THE
COMMANDER SUFFERED A RECURRENCE OF A BACK STRAIN FROM
A ROLL OF THE RECOVERY SHIP -- POSSIBLY ANOTHER
DEMONSTRATION OF THE HAZARD OF MUSCLE DECONDITIONING.
ALTHOUGH THERE IS A RELATIVE IMPROVEMENT IN LOSS OVER
SKYLAB 2, THERE NEVERTHELESS REMAINS A SIGNIFICANT

(REDUCTION.)

MUSCLE - II

REDUCTION. IT SEEMS RATHER OBVIOUS THAT THE "MK I" AND "MK II" EXERCISE DEVICES DID A GOOD JOB IN ARM PRESERVATION BUT WERE STILL INADEQUATE TO MAINTAIN LEG FUNCTION.

SOME DEVICE WHICH ALLOWED WALKING AND RUNNING UNDER THE EQUIVALENT FORCES OF GRAVITY APPEARED TO BE THE IDEAL ANSWER TO THIS PROBLEM AND IMMEDIATELY AFTER SL-2, WORK WAS STARTED ON A TREADMILL FOR SKYLAB 4.

SLIDE 2-8

IT CONSISTED OF AN ALUMINUM TEFLON WALKING SURFACE ATTACHED TO THE ISO-GRID FLOOR. FOUR RUBBER BUNGEEES PROVIDING AN EQUIVALENT WEIGHT OF 175 POUNDS WERE ATTACHED TO A SHOULDER AND WAIST HARNESS. BY ANGLING THE BUNGEEES, AN EQUIVALENT TO A SLIPPERY HILL IS PRESENTED TO THE SUBJECT WHO MUST CLIMB IT. HIGH LOADS WERE PLACED ON SOME LEG MUSCLES, ESPECIALLY IN THE CALF,

(AND FATIGUE)

AND FATIGUE WAS RAPID SUCH THAT IT COULD NOT BE USED
FOR SIGNIFICANT AEROBIC WORK.

FILM CLIP:
Treadmill

(NARRATE)

(AS THE MISSION PROGRESSED, LAUNCH WEIGHT OF
SKYLAB 4 BECAME CRUCIAL SUCH THAT THE FINAL DESIGN
WAS SIMULATION OF A TREADMILL IN RESPONSE TO THE WEIGHT
CONSTRAINTS -- FINAL WEIGHT FOR THE DEVICE WAS 3 1/2
POUNDS.)

ON SKYLAB 4, THE CREW USED THE BICYCLE ERGOMETER
AT ESSENTIALLY THE SAME RATE AS SKYLAB 3, AND THE MK I AND II
EXERCISERS. IN ADDITION, THEY TYPICALLY PERFORMED TEN
MINUTES PER DAY OF WALKING, JUMPING, AND JOGGING ON
THE TREADMILL. FOOD INTAKE HAD AGAIN BEEN INCREASED.

EVEN PRIOR TO MUSCLE TESTING, IT WAS OBVIOUS THAT
THE SKYLAB 4 CREW WAS IN SURPRISINGLY GOOD CONDITION.

(THEY STOOD)

THEY STOOD AND WALKED FOR LONG PERIODS WITHOUT APPARENT DIFFICULTY ON R+1 IN CONTRAST TO THE EARLIER MISSIONS. RESULTS OF THE TESTING CONFIRMED A SURPRISINGLY SMALL LOSS IN LEG STRENGTH FOR ALMOST THREE MONTHS IN WEIGHTLESSNESS. A SUMMARY OF THE EXERCISE AND STRENGTH TESTING IS SHOWN ON THIS SLIDE

OF AVERAGED VALUES FOR THE THREE MISSIONS. ONE POINT TO BE NOTED IS THE RELATIVELY SMALL LOSSES IN ARMS AS COMPARED TO LEGS IN ALL MISSIONS. THIS IS REASONABLE FOR IN SPACE ORDINARY WORK PROVIDES LOADS FOR THE ARMS THAT ARE RELATIVELY MUCH GREATER. THE LEGS RECEIVE VIRTUALLY NO EFFECTIVE LOADING. WITH THE MK I AND II EXERCISERS, ARM LOSSES WERE REDUCED TO NEGLIGIBLE VALUES EXCEPT IN ARM EXTENSORS ON SKYLAB 4, MOST OF WHICH WAS ACCOUNTED FOR BY THE COMMANDER. THE

SLIDES

2-9
and
2-10

(NEXT TIME)

NEXT TIME JERRY FLIES, I MUST SPEAK TO HIM ABOUT THAT.

SLIDE 2-11

2-11

SIZE IS ANOTHER COMMON MEASURE OF MUSCLE CONDITION, AND A PLOT OF AVERAGE CHANGE IN LEG VOLUME FOR EACH CREW IN THE POST-FLIGHT PERIOD IS SHOWN. CHANGES FOR THE FIRST TWO DAYS MUST BE PRIMARILY FLUID. SL-2 AND 3 LOST ESSENTIALLY THE SAME VOLUME IN SPITE OF A 2-FOLD DIFFERENCE IN MISSION DURATION, WHILE THE LONGEST MISSION LOST ONLY 1/2 OF THE VOLUME OF THE SHORTER ONES. A SECOND POINT IS THAT SL-4 QUICKLY RECOVERED THEIR PRE-FLIGHT VOLUME IN CONTRAST TO 2 AND 3. NOTICE THAT THIS DATA PARALLELS THAT OF LEG EXTENSOR STRENGTH LOSSES WHICH WERE ROUGHLY EQUAL ON SL-2 AND 3, AND SHARPLY REDUCED ON 4.

THERE WAS A 6 1/2 TO 9-FOLD REDUCTION IN RATE OF LOSS OF LEG EXTENSOR STRENGTH, LEG VOLUME, LEAN BODY MASS AND TOTAL BODY MASS FROM SL-2 TO SL-4. ONE MIGHT

(ARGUE THAT)

ARGUE THAT THIS REDUCTION SIMPLY REPRESENTS SOME KIND OF EQUILIBRIUM WITH INCREASING MISSION DURATION, BUT THIS IS NOT CONSISTENT WITH THE NEXT CHART WHICH

²
SLIDE 2-1

SHOWS ABSOLUTE LOSSES. AGAIN, SL-4 SHOWS A MARKED IMPROVEMENT AS REGARDS WEIGHT, LEG STRENGTH AND LEG VOLUME. I FEEL CORRECT IN ATTRIBUTING THE DECREASE IN LOSS OF MUSCLE STRENGTH AND BULK TO THE EXERCISE DEVICES AND TIME THAT WAS ADDED. THERE CAN BE LITTLE DOUBT THAT ADDING THE MK I AND II IMPROVED THE ARM PERFORMANCE OF SL-2 AND 3; AND EQUALLY LITTLE DOUBT THAT THE TREADMILL SHARPLY REDUCED LOSS OF LEG STRENGTH AND MASS, SINCE THERE WAS NEGLIGIBLE INCREASE IN LEG EXERCISE WITH OTHER DEVICES ON SL-4. HOWEVER, IT MUST BE RECOGNIZED THAT ANOTHER VARIABLE WAS PRESENT -- FOOD.

(VIRTUALLY ALL)

VIRTUALLY ALL WORKERS IN NUTRITION -- THAT I KNOW --
RECOGNIZE THAT METABOLIC LOSSES IN NORMAL SUBJECTS
ARE MIXED, i.e., BOTH FAT AND MUSCLE ARE LOST.

VANDERVEEN AND ALLEN DELIBERATELY REDUCED CALORIC
INTAKE DURING A 1-G CHAMBER TEST SIMULATION OF SPACE
FLIGHT CONDITIONS USING SUBJECTS CHOSEN TO BE AS
EQUIVALENT AS POSSIBLE TO THE ASTRONAUT POPULATION.
THEY FOUND AN ALMOST PURE MUSCLE LOSS.

AT THIS TIME, I CANNOT ESCAPE THE CONCLUSION THAT
MUSCLE IN SPACE IS NO DIFFERENT FROM MUSCLE ON EARTH,
IF IT IS PROPERLY NOURISHED AND EXERCISED AT REASONABLE
LOAD LEVELS, IT WILL MAINTAIN ITS FUNCTION.

I FEEL THAT A PROPERLY DESIGNED TREADMILL USED
FOR CONSIDERABLY LESS THAN AN HOUR A DAY WILL NOT ONLY
PROTECT LEG AND TRUNK MUSCULATURE, BUT WILL ALSO

(PROVIDE AEROBIC)

PROVIDE AEROBIC EXERCISE TO COVER THE CARDIO-RESPIRATORY SYSTEM. IT WILL NOT BE DIFFICULT TO ADD ARM EXERCISE AT THE SAME TIME SUCH THAT WE MEET THE REQUIREMENTS FOR A SINGLE TOTAL BODY EXERCISER.

THE MUSCLE-SYSTEM IS RIGHTLY DESCRIBED AS THE MUSCULO-SKELETAL SYSTEM SINCE THEY ARE INSEPARABLE. WHILE I WOULD NOT DARE COMMENT ON THE CA + ION AND ITS DYNAMICS -- I WILL SAY THAT BONE-LIKE MUSCLE, WHEN PROPERLY STRESSED AND NOURISHED, WILL IN ALL PROBABILITY RETAIN ITS STRENGTH. BED REST STUDIES NOT WITHSTANDING, IT SEEMS ENTIRELY POSSIBLE TO DESIGN SUCH STRESSORS THAT ARE COMPATIBLE WITH SPACE FLIGHT.

In summary I feel we have demonstrated that ~~moder~~ muscle in space behaves very much like muscle on earth and the same principles ~~for~~ conditioning + deconditioning holds. Exercise devices to protect ~~most of~~ ^{too much of} the body's skeletal muscle. It ~~will be~~ ^{is} practical to design fly exercise devices or device which

LIST OF SLIDES - MASS

NUMBER	TITLE
1 - 1	Schematic Spring/Mass Oscillator
2	Cal. curve SMMD
3	Variation 50 gm. Cal pt. SMMD
4	Body mass Skylab 2 Commander
5	Body mass Skylab 2 Pilot
4-A	Body mass Skylab 2 Science Pilot
6	Body mass Skylab 3 Commander
7	Body mass Skylab 3 Science Pilot
6-A	Body mass Skylab Pilot
8	Body mass Skylab 4 Commander
8-A	Body mass Skylab 4 Pilot
8-B	Body mass Skylab 4 Science Pilot
9	Weight loss versus Caloric intake
10	Body weight change, insertion and recovery Skylab 3
11	Body weight change, insertion and recovery Skylab 4

CORRECTIONS - MASS SLIDES

- 4748-1) move 1 to spring/mass versus mass/oscillator
- 2) remove "motion equation"
- 4801 change time, sec. to time, sec.²
- 4756 remove "On Skylab Diet"
- 4757 remove "On Skylab Diet"
- 4758 remove "On Skylab Diet"
- 4759 remove "On Skylab Diet"
- 4760 remove "On Skylab Diet"
- 4764 remove "On Skylab Diet"
- 4761 remove "On Skylab Diet"
- 4762 remove "On Skylab Diet"
- 4763 remove "On Skylab Diet"