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PREPARED FOR
ENGINEERING PSYCHOLOGY BRANCH
OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
WASHINGTON, D. C.
CONTRACT NONR-2856(00)

5-1

A METHOD OF MAKING
DIMENSIONAL MEASUREMENTS OF COMPLEX MOTIONS

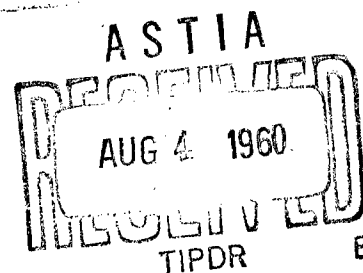
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20061016183

R & C REPORT #60-1-2
31 MARCH 1960



ABSTRACT

A *is* *whereby*
USING THE METHOD DESCRIBED IN THE REPORT, DETERMINATION CAN BE MADE OF
THE FOUR DIMENSIONAL COORDINATES OF ANY GIVEN POINT OF INTEREST. THIS
IS ACCOMPLISHED THROUGH ADJUSTING THE IMAGE SIZE OF A ONE-CAMERA MOTION
PICTURE PHOTOGRAPHIC VIEW OF A SPHERE SO THAT IT IS RECONSTITUTED IN
ACTUAL SIZE. THIS RESTORATION OF CORRECT PROJECTION SIZE SIMULTANEOUSLY
SOLVES ALL THE PROBLEMS OF PARALLAX WHICH HAVE PREVIOUSLY BLOCKED
PRACTICAL PHOTOGRAPHIC MEASUREMENTS OF THIS KIND. USE OF THE METHOD
PERMITS PHOTOGRAPHIC RECORDING AND RESULTANT READOUT OF THE ENVELOPE OF
SPACE REQUIRED FOR THE EXECUTION OF COMPLEX MOTIONS.

IN ORDER TO DEMONSTRATE THE VERSATILITY OF THE TECHNIQUE, FOUR DIFFERENT
TASKS WERE PHOTOGRAPHED: (1) WALKING [ONE PERSON AT A TIME]; (2) A TWO-
MAN DUTY STATION REPLACEMENT INTERACTION IN WHICH ONE MAN APPROACHES THE
SECOND, WHO WAS SEATED, AND REPLACED HIM AT THIS STATION; (3) A LIFT-
CARRY-PUT OPERATION [ONE PERSON AT A TIME]; ^{and} (4) THE SAME TASK PERFORMED
BY TWO MEN SIMULTANEOUSLY. THE SUBJECTS USED IN THESE TASKS WERE
APPROXIMATELY REPRESENTATIVE OF THE 5TH AND 95TH PERCENTILE AMERICAN
MALE IN TERMS OF MAJOR BODY DIMENSIONS. THE INFLUENCE OF FATIGUE ON
THEIR TASK PERFORMANCE WAS EXAMINED.

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Processed data portraying the exterior dimensions of the total space envelopes required by the human for certain tasks are presented. Although the technique has been demonstrated using human biomechanical motions, there is no apparent reason why the technique could not be applied to mechanical motions in general.

ACKNOWLEDGEMENTS

SPECIFIC MENTION SHOULD BE MADE OF THE ENCOURAGEMENT AND COUNSEL PROVIDED TO US BY DR. MAX LUND AND DR. PAUL CHEATHAM OF THE OFFICE OF NAVAL RESEARCH. THEIR TRUST IN OUR SELF-PROCLAIMED ABILITY TO ACHIEVE A WORKABLE SOLUTION TO A LONG STANDING AND DIFFICULT METHODOLOGICAL PROBLEM HAS BEEN A SUSTAINING INFLUENCE AGAINST THE USUAL FORTUITIES OF RESEARCH.

WE HAVE BEEN ASSISTED IN THE EXECUTION OF THIS RESEARCH BY MESSRS. WILLIAM BASS (PHYSICAL ANTHROPOLOGIST), DOUGLAS CORNOG (HUMAN FACTORS SPECIALIST) AND DR. WILLIAM ANGOFF (STATISTICIAN) WHO MADE CONSULTATIVE CONTRIBUTIONS, AND BY MESSRS. JOHN LAZO AND THOMAS GALLAGHER, OF THE AIR CREW EQUIPMENT LABORATORY, WHO ASSISTED IN PROVIDING EXPERIMENTAL SUBJECTS. MISS DOLORES KOLIBAB ATTENDED TO THE MYRIAD DETAILS OF PUBLICATION.

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A METHOD FOR MAKING DIMENSIONAL MEASUREMENTS OF COMPLEX MOTIONS

SECTION ONE

INTRODUCTION

HUMAN FACTORS SPECIALISTS ARE FREQUENTLY CALLED UPON FOR DATA REGARDING THE AMOUNT OF SPACE WHICH IS REQUIRED FOR THE EXECUTION OF SOME ACTIVITY. FURTHER, THEY MAY BE ASKED TO LAY OUT SPECIFIC WORK AREAS SUCH AS CONSOLES, SEATING ARRANGEMENTS, OR COMPARTMENTS. IN ORDER TO ACCOMPLISH THIS WORK ON AS RATIONAL A BASIS AS POSSIBLE, THE HUMAN FACTORS SPECIALIST COMMONLY TURNS TO THE DATA COLLECTED BY THE PHYSICAL ANTHROPOMETRIST. WHEN THIS IS ATTEMPTED, A VERY UNFORTUNATE LIMITATION SOON BECOMES APPARENT. THE VAST MAJORITY OF THE DATA WHICH IS AVAILABLE HAS BEEN COLLECTED ON STATIC HUMANS WHO ARE POSED IN HIGHLY STANDARDIZED POSTURES. STANDARDIZATION AND IMMOBILIZATION HAVE LED TO CERTAIN DESIRABLE OBJECTIVES, AT LEAST THEY ARE DESIRABLE FROM CERTAIN STANDPOINTS---THE DATA HAS BEEN RELATIVELY EASILY OBTAINED AND IS REASONABLY RELIABLY OBTAINED. HOWEVER, SINCE THE HUMAN BODY FLAILS, BOBS, WOBBLER, SWAYS, WEAVES, PITCHES, ETC., AS IT MOVES ABOUT IN REAL LIFE ACTIVITY, IT IS NOT AT ALL UNCOMMON TO FIND THAT MEASURES WHICH HAVE BEEN OBTAINED STATICALLY BEAR LITTLE RESEMBLANCE TO THE ACTUAL ENVELOPE OF SPACE WHICH IS REALLY OCCUPIED BY THE ACTIVE, PURPOSEIVE HUMAN. IN RECOGNITION OF THESE LIMITATIONS, THE PRESENT RESEARCH WAS UNDERTAKEN.

THE PRIMARY PURPOSE OF THIS RESEARCH WAS TO DEVELOP A METHOD OF MEASUREMENT WHICH WOULD CREATE PRACTICAL, IMMEDIATELY USEFUL DATA ON THE DYNAMIC

SPACE REQUIREMENTS OF THE HUMAN AND, TO THE EXTENT POSSIBLE, COLLECT EXAMPLES OF SUCH DATA.

THE SPACE REQUIREMENTS OF THE MOBILE OPERATOR SHOULD FIRST BE DEFINED. THE REQUIREMENTS REFERRED TO ARE THE MAXIMUM LIMITS OF THE FOUR-DIMENSIONAL ENVELOPE OF SPACE WHICH THE OPERATOR OCCUPIES IN THE COURSE OF PERFORMING A TASK. THUS, AS THE MAN GOES ABOUT HIS WORK, HE CIRCUMSCRIBES AN UNDULATING, IRREGULAR, FOUR-DIMENSIONAL SPACE ENVELOPE. ALL OF HIS PHYSICAL ACTIVITIES WHILE ENGAGED IN A SPECIFIC TASK COULD BE CONTAINED WITHIN THIS ODD-SHAPED ENVELOPE. IT IS IMMEDIATELY APPARENT THAT CONCRETE DATA ON THE CHARACTERISTICS OF THIS ENVELOPE WOULD BE QUITE VALUABLE IN DELINEATION OF THE TIME-SHARING AND SPACE-SHARING OPPORTUNITIES AVAILABLE TO SPECIALISTS WHO ARE ENGROSSED WITH SPACE LAYOUT PROBLEMS, TIME AND MOTION STUDIES, ACTIVITY ANALYSES, AND SO FORTH.

ACTUALLY, THE COLLECTION OF REALISTIC DATA DESCRIBING HUMAN SPACE REQUIREMENTS HAS BEEN A LONG RECOGNIZED NEED. THIS NEED HAS BEEN ONLY PARTLY SATISFIED BY INFORMATION AVAILABLE IN STUDIES FROM THE FIELDS OF ANATOMY AND PHYSICAL ANTHROPOLOGY.¹ MOST OF THESE STUDIES HAVE PRODUCED MEASUREMENTS WHICH ARE MAINLY APPLICABLE TO SEDENTARY, NON-MOBILE RELATIONSHIPS.

1. THERE IS NO ATTEMPT HEREIN TO COMPLETELY REPORT ALL OF THE KNOWN RELEVANT LITERATURE. ONE OF THE CONSULTANTS OF THIS COMPANY (CORNOG) HAS RECENTLY ACCOMPLISHED AN EXCEPTIONALLY COMPREHENSIVE REVIEW OF THIS SUBJECT. (HANSEN & CORNOG, 1958) THERE WOULD APPEAR TO BE NO JUSTIFICATION IN CONSUMING SPACE TO SIMPLY RECOUNT HIS EARLIER WORK.

BETWEEN MAN AND HIS ENVIRONMENT. BASIC STUDIES SUCH AS THAT BY DEMPSTER (JULY, 1955) HAVE ESTABLISHED A NUMBER OF PARAMETERS OF BODY MOVEMENTS. LARGE SCALE ANTHROPOMETRIC MEASURING PROGRAMS SUCH AS THOSE CARRIED ON BY HERTZBERG, DANIELS, AND CHURCHILL (1954) HAVE OBTAINED A WEALTH OF STATIC PHYSICAL DIMENSIONAL DATA AND THE SIZES AND RANGES OF THIS DATA WITHIN THE STUDIED POPULATIONS. HOWEVER, MORANT (1947) STATED THAT BY THEMSELVES, BODY MEASUREMENTS CANNOT GIVE ANY PRECISE ANSWER TO QUESTIONS OF WHAT SURROUNDING DIMENSIONS SHOULD BE OR WHERE CONTROLS SHOULD BE BEST PLACED. OTHER FACTORS MAY BE INVOLVED. KING, ET AL (1945) SHOWED THAT STANDARD ANTHROPOMETRIC DATA ALONE ARE USUALLY INADEQUATE FOR THE EFFICIENT DESIGN OF WORK SPACES IN AIRCRAFT. ELFTMAN (1943, 1951) STUDIED THE DYNAMIC PATTERN OF HUMAN LOCOMOTION, GETTING CLOSER TO THE SOLUTION OF THE PROBLEM, ALTHOUGH NO DEFINITE SPACE REQUIREMENTS DATA WERE GENERATED.

DEMPSEY (1953) DESCRIBED A WORKSPACE MEASURING DEVICE WHICH WAS DEVELOPED TO DETERMINE THE MAXIMUM, MINIMUM, AND OPTIMUM SPACE REQUIREMENTS OF AIR FORCE PILOTS WHEN SEATED IN THE COCKPIT SITUATION; AND TO SIMULATE IN THE LABORATORY EXISTING OR PROPOSED COCKPIT DESIGNS WITH AN EYE TO PROPER SPACE UTILIZATION. HERTZBERG, DANIELS, AND CHURCHILL (1954) INCLUDED SEVERAL NEW-TYPE MEASUREMENTS IN THEIR STUDY TO PERMIT MOBILITY MEASUREMENTS TO INDICATE THE "SPACE ENVELOPE"² THROUGH WHICH A MAN MOVES TO PERFORM HIS FLIGHT TASKS. HERTZBERG, DUPERTUIS, AND EMANUEL (1958)

2. HERTZBERG, WHO HAS BEEN A PIONEER AND CHAMPION OF FUNCTION ANTHROPOMETRY, ORIGINATED THE "SPACE ENVELOPE" CONCEPT USED HEREIN. FOR HIS CONCEPT AND FOR HIS INITIAL EFFORTS TO MEASURE DYNAMIC ANTHROPOMETRICS THE PROFESSION IN GENERAL IS DEEPLY INDEBTED.

REFINED PHOTOGRAMMETRY AS A TOOL, USING A STEREOSCOPIC METHOD TO OBTAIN BODY PROPORTIONS, DIAMETERS, AND SURFACE FORM AND DIMENSIONS FOR STATIC SUBJECTS IN VARIOUS POSITIONS. A PHOTOGRAPHIC METHOD USED BY KOBRICK (1956 ET. SEQ.) TO RECORD THE SPATIAL DIMENSIONS OF SUBJECTS FOR THE PURPOSE OF DESIGNING EQUIPMENT WAS APPLICABLE ONLY FOR POSED BODY POSITIONS.

IT IS KNOWN, BOTH FROM THE LITERATURE AND FROM PERSONAL OBSERVATIONS, THAT WHEN DESIGNERS TRY TO USE STANDARD ANTHROPOMETRIC DATA ALONE TO INFER THE SPACE REQUIREMENTS OF PEOPLE AS THEY MOVE ABOUT, THEY DO NOT FIND THEM SUFFICIENT IN ALL RESPECTS. THE STATIC DATA FAILS TO PROVIDE COMPLETE INSIGHT INTO THE PECULIAR AND CHANGING MOTIONS OF PEOPLE AS THEY GO ABOUT COMPLEX AND RELATIVELY UNSTRUCTURED TASKS. ATTEMPTS TO USE "LIGHT-STREAK" OR "SEQUENCED-FLASH" TECHNIQUES HAVE BEEN REASONABLY SUCCESSFUL IN SHOWING THE DYNAMIC PATTERNS OF MOTION. THESE TECHNIQUES HAVE NOT BEEN ABLE TO GIVE RELIABLE DATA ON DIMENSIONS. THIS HAS BEEN A RATHER SEVERE LIMITATION. ONE ATTEMPT AT CIRCUMVENTING THE PROBLEM HAS BEEN TO COMBINE STATIC MEASUREMENTS AND THEN TACK ON AN ADDITIONAL ALLOWANCE TO COMPENSATE FOR MOTION. WHILE THIS APPROACH WORKS ADEQUATELY IN SIMPLE SITUATIONS, IT IS RATHER SEVERELY RESTRICTED IN APPLICABILITY, SINCE THERE IS RELATIVELY POOR DATA ON THE AMPLITUDES, RATIO, AND PERIODS OF BODY MOTIONS. ACCORDINGLY, ONE CANNOT USE THE RIGHT CORRECTION FACTORS. STILL OTHER ATTEMPTS HAVE BEEN MADE TOWARD DYNAMIC ANTHROPOMETRY, MANY OF THEM PHOTOGRAPHIC IN CONCEPT, BUT ALL HAVE BEEN RELATIVELY UNRELIABLE AND INVALID AS MEASURING STRATEGY. AT LEAST THEY ARE NOT COMPLETELY SUITED TO THE PURPOSE UNDER DISCUSSION HERE.

REDUCED TO SIMPLEST TERMS, THE SCIENTIFIC COMMUNITY HAS NOT ACHIEVED GOOD DYNAMIC ANTHROPOMETRIC DATA FOR THE SIMPLE REASON THAT THERE HAS NOT BEEN A FEASIBLE METHOD TO OBTAIN SUCH DATA ON A RELIABLE AND VALID BASIS. IT HAS BEEN THE PRIME OBJECTIVE OF THE PRESENT RESEARCH TO DEVISE AND DEVELOP SUCH A METHOD.

SECTION TWO

DEVELOPMENT OF METHODOLOGY

DEVELOPMENT OF A METHOD FOR OBTAINING VALID AND RELIABLE PHYSICAL ANTHROPOMETRIC DATA BEING THE PRIMARY OBJECTIVE OF THIS PROJECT, THE STAFF QUITE NATURALLY DEVOTED EXTENSIVE TIME TO DEVISING WAYS AND MEANS TO INSTRUMENT THE MEASURING SITUATION. IF ONE IS TO MEASURE ACTIONS OF THE HUMAN, IT IS CLEARLY UNDESIRABLE THAT ANY ARTIFICIAL PHYSICAL CONSTRAINTS BE PLACED UPON THE SUBJECT. THIS RULES OUT WIRES, PULLEYS, BRUSHES, PROBES, LEVERS, AND SIMILAR ATTACHMENTS TO THE PERSON. ALSO, SINCE THEY WOULD AFFECT THE NORMALCY OF THE WORK, FILAMENTS, SMOKES, FRANGIBLE SEMI-SOLID MEMBRANES THROUGH WHICH THE OPERATOR PASSED, BRUSHED OR TRAILED, WERE SOON REJECTED. SINCE RESEARCH IS ALREADY UNDERWAY ELSEWHERE ON ELECTRONIC MEASUREMENT, THAT AREA WAS PURPOSELY AVOIDED. SOUND AND ULTRASONICS WERE CONSIDERED. ANOTHER IDEA, MORE SOPHISTICATED THAN THE ONE REPORTED HERE AND CENTERING AROUND AN ELECTRONIC SYSTEM TIED TO A COMPUTER, HAS BEEN CONCEIVED BY ONE OF THE WRITERS. HOWEVER, IT IS STILL IN THE DEVELOPMENTAL STAGES AND NEED NOT BE DISCUSSED HERE.

AS THE FEASIBILITY OF VARIOUS TECHNIQUES WAS CONSIDERED, THE RESEARCH GROUP WAS GRADUALLY LED BACK AGAIN AND AGAIN TO MOTION PICTURE PHOTOGRAPHY AS THE TECHNIQUE MOST LIKELY TO PRODUCE USABLE RESULTS WITHIN REASONABLE DEVELOPMENT COST. THERE WERE A NUMBER OF ADVANTAGES WHICH COULD BE EXPECTED IF SUCH A TECHNIQUE COULD BE DEVELOPED. FOR EXAMPLE, SOME OF THE ADVANTAGES ARE: (1) AVAILABILITY OF EQUIPMENT. MOST LABORATORIES HAVE

16 MM MOTION PICTURE GEAR. THOSE WHO DO NOT CAN OBTAIN SUCH GEAR ON A RENTAL OR PURCHASE BASIS AT LOW OVERALL COST. THE USE OF PHOTOGRAPHY PROVIDES TANGIBLE RECORDS WHICH MAY BE EXAMINED AND RE-EXAMINED BY DIFFERENT PEOPLE, EACH OF WHOM CAN STUDY SPECIFIC ISSUES WITH NO DAMAGE TO THE DATA. (2) DATA IS PERMANENT, EASILY STORED AND CAN BE COPIED READILY. A WIDE VARIETY OF RECORDING TECHNIQUES ARE AVAILABLE BY INTER-COMBINATIONS OF LENSES, FILMS, SPEEDS, LIGHTING, PROCESSING, AND OTHER VARIABLES WHICH ARE AVAILABLE TO THE PHOTOGRAPHER. IN ADDITION---AND THIS IS A SIGNIFICANT POINT---DATA COLLECTION AND DATA REDUCTION CAN BE ACCOMPLISHED BY RELATIVELY UNSKILLED PERSONNEL. FOR THESE AND OTHER SIMILAR REASONS, IT WAS DECIDED TO CONCENTRATE ON PHOTOGRAPHIC TECHNIQUES.

THE ITEM WHICH HAS PROVEN TO BE THE WORST SINGLE BARRIER IN PRIOR PHOTOGRAMMETRIC ATTEMPTS WOULD SEEM TO BE THE PARALLAX WHICH IS BROUGHT ABOUT BY THE GEOMETRIC RELATIONSHIPS WHICH ARE INHERENT IN THE OPTICAL SYSTEMS AND REPRODUCTION PRACTICES. THE RESEARCH REPORTED HERE DISCLOSES A WAY TO SOLVE THIS PERSISTENT PROBLEM OF OPTICAL PARALLAX.

FIRST, IT IS NECESSARY TO OBTAIN A CLEAR UNDERSTANDING OF WHAT IS MEANT BY PARALLAX AS IT IS USED HERE. THE PARALLAXES MOST COMMONLY MENTIONED IN THE PSYCHOLOGICAL LITERATURE ARE MOTION PARALLAX AND BINOCULAR PARALLAX. THE PHENOMENON FOUND HEREIN IS AN OPTICAL PARALLAX AND IS UNRELATED TO THOSE IN THE FIELD OF PSYCHOLOGY.

FIGURES 1, 2, AND 3 WILL ASSIST IN UNDERSTANDING THE PROBLEM AND HOW IT HAS BEEN OVERCOME IN THIS METHODOLOGY. FIGURE 1 SHOWS A SITUATION IN

FIGURE 1
RELATIONS OF OBJECTS AS PHOTOGRAPHED

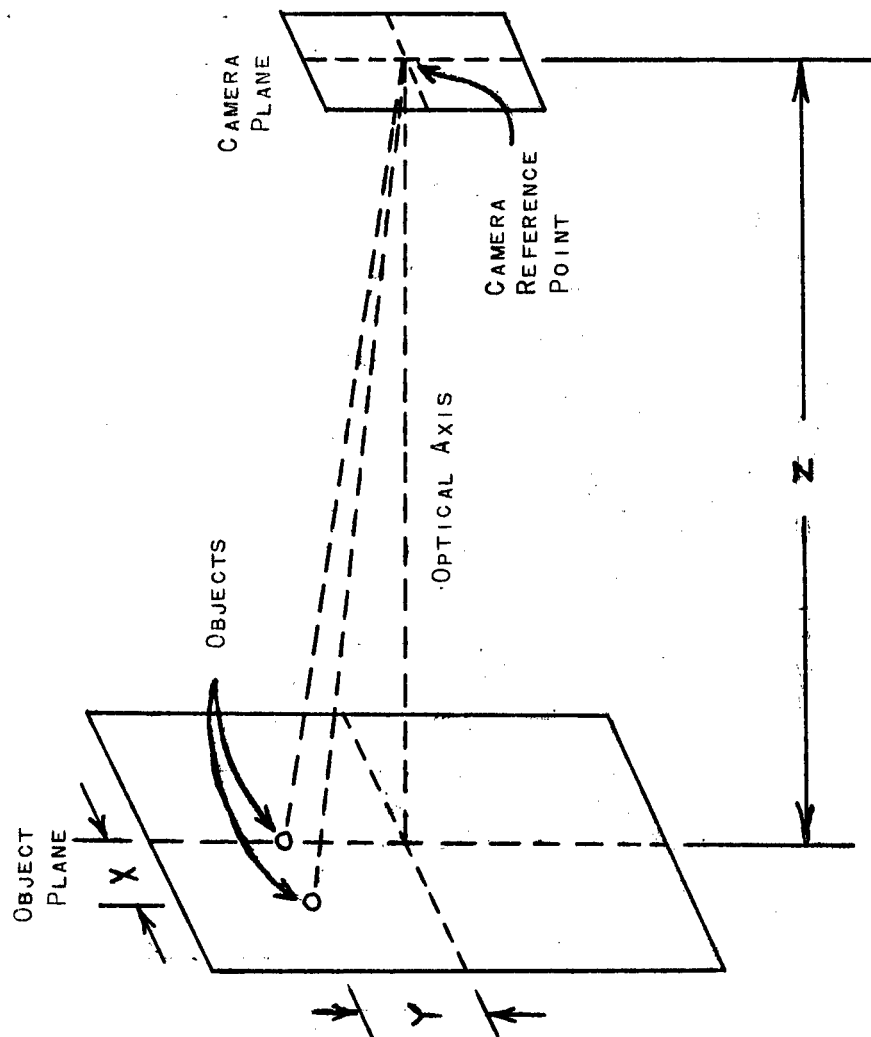


FIGURE 2

RELATIONS OF IMAGES OF OBJECTS AS PROJECTED
SHOWING DEVELOPMENT OF PARALLAX

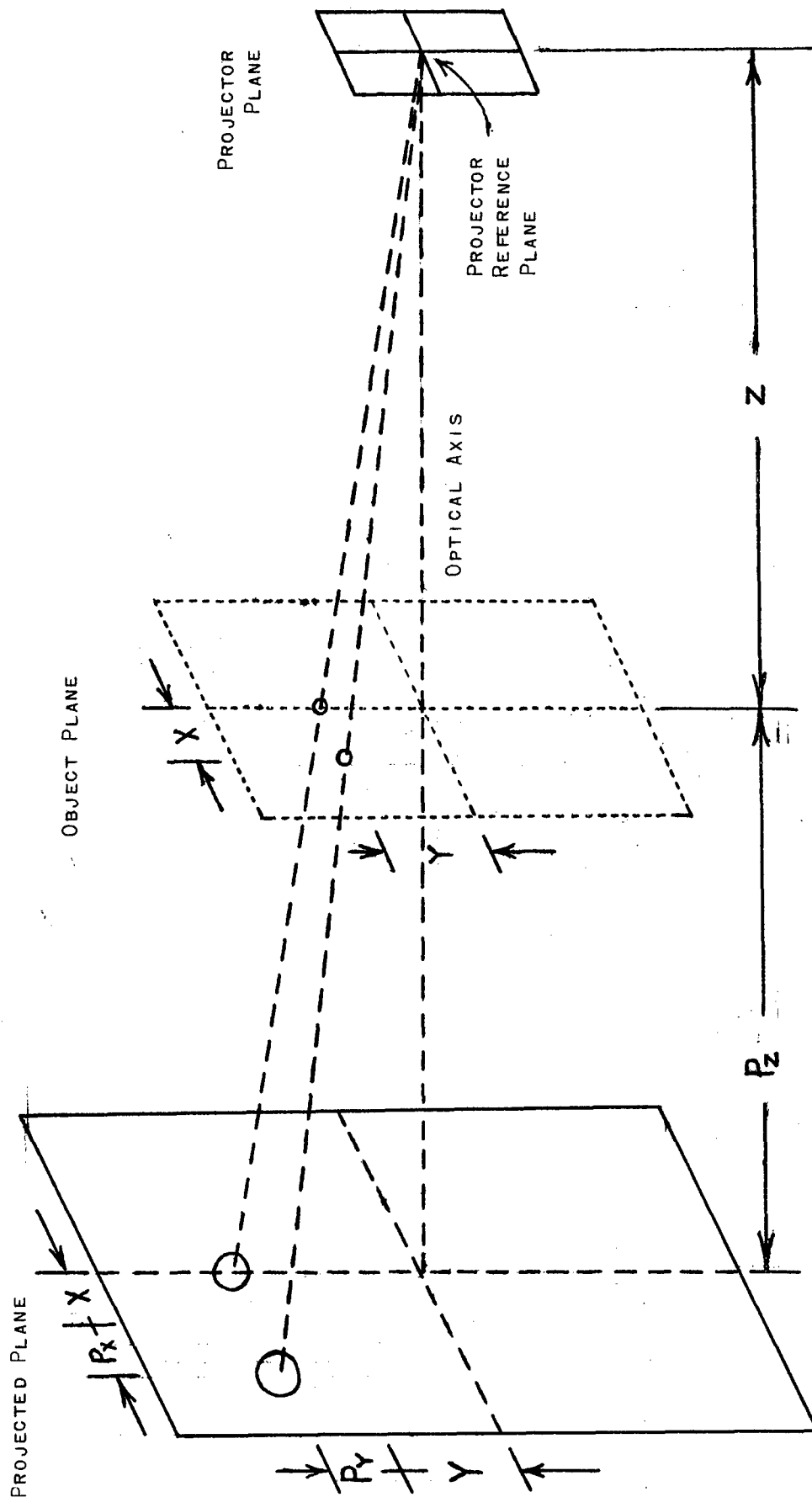


FIGURE 3

SHOWING THAT CORRECT LOCATION OF PROJECTION PLANE SO AS TO RESTORE CORRECT OBJECT SIZE WILL SIMULTANEOUSLY RESTORE CORRECT SPATIAL COORDINATES WHICH EXISTED IN ORIGINAL SCENE

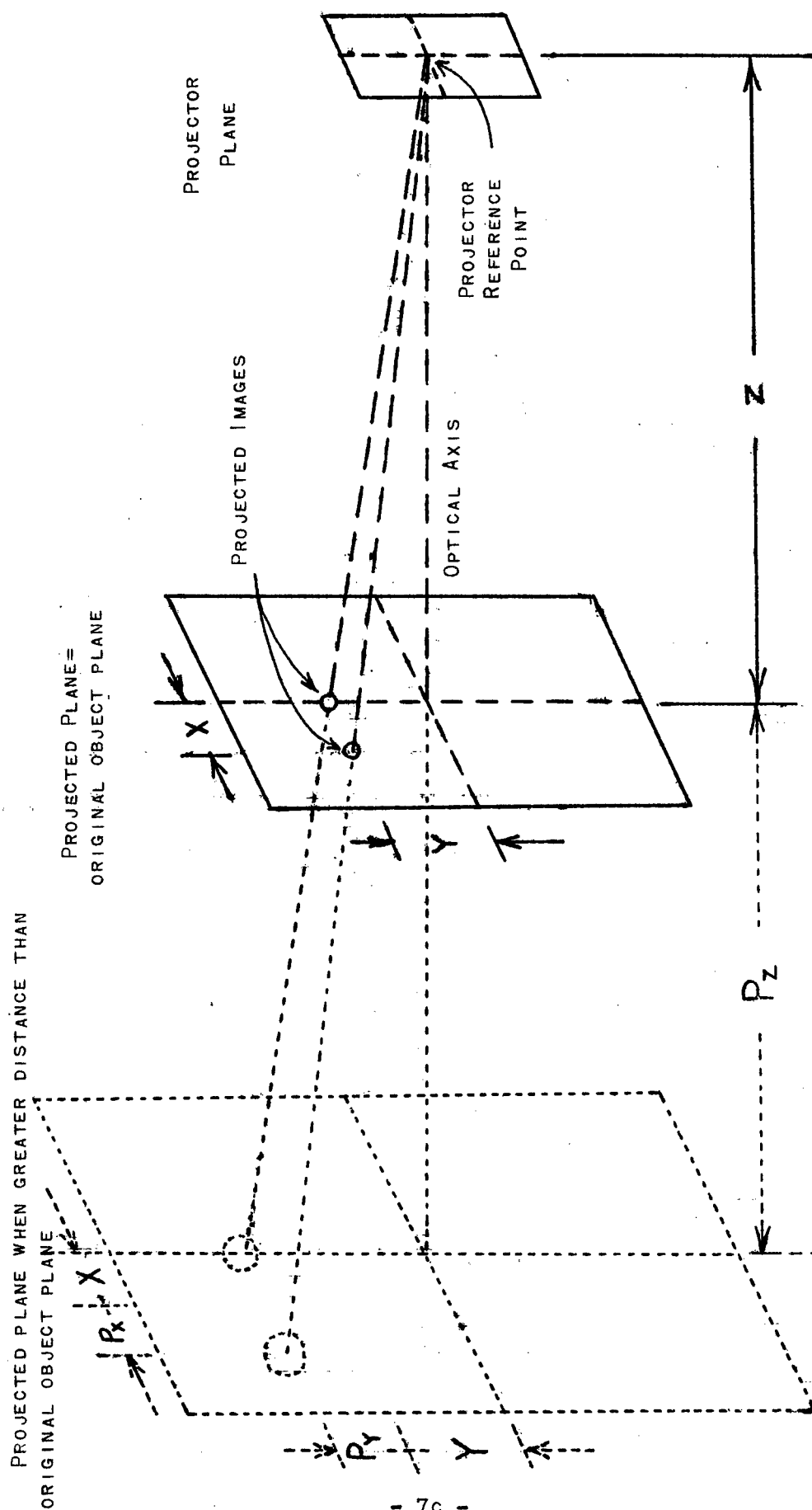
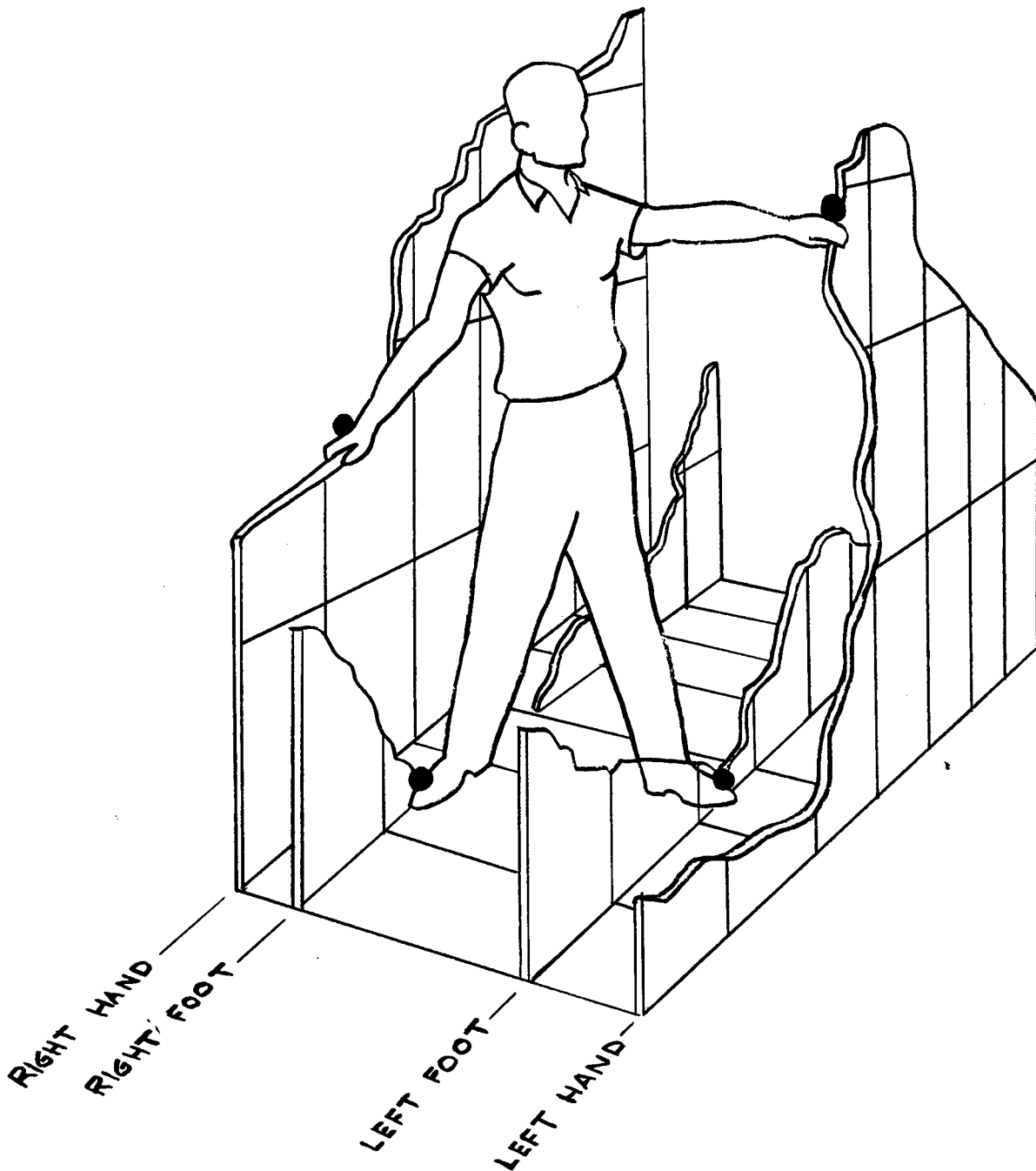


FIGURE 4

MULTIPLICITY OF PLANES OCCUPIED BY A BODY

(EACH PLANE CAN BE IDENTIFIED BY ADJUSTING SIZES OF SPHERICAL REFERENCES
AT EACH PLANE)



WHICH A MAN IS BEING PHOTOGRAPHED. THE PERSON IS ACTUALLY IN MANY PLANES AT ONCE (SEE FIGURE 4) BUT, FOR PRESENT PURPOSES, LET US MERELY EXAMINE A COUPLE OF POINTS. ASSUME THAT THE MOTION PICTURE CAMERA IS LOCATED AT THE INTERSECTION OF THREE PLANES AT A GIVEN MOMENT IN TIME. ASSUME THAT THE OPTICAL AXIS IS PERPENDICULAR TO THE VERTICAL PLANE, BISECTS THE HORIZONTAL PLANE, AND RUNS PARALLEL TO THE LONGITUDINAL (FLOOR OR CEILING) PLANE. ASSUME THAT THE OPTICAL AXIS MAINTAINS THE SAME RELATIONSHIP TO THE PLANE (OR PLANES) WHICH CONTAINS THE SUBJECT OR, AS WILL BE SEEN LATER, THE PLANE CARRYING THE PROJECTED PHOTOGRAPHIC IMAGES OF SUBJECTS. A MOMENT OF REFLECTION WILL REVEAL THAT A COMPLETELY EUCLIDIAN GEOMETRIC RELATIONSHIP HAS NOW BEEN POSTULATED IN WHICH SUCCESSIVE LAYERS, ROWS, AND COLUMNS OF SPACE ARE NEATLY ARRANGED PARALLEL AND PERPENDICULAR TO A SET OF RECTILINEAR TRIDIMENSIONAL CORRELATES OF PHYSICAL SPACE. NOW ASSUME THAT THERE IS A SUBJECT ON THE SUBJECT PLANE AND THAT THERE IS AN INTEREST IN TWO POINTS ON THAT SUBJECT. ONE POINT IS ON HIS CENTER LINE SOMEWHAT ABOVE THE OPTICAL AXIS (SAY AT HIS THROAT). THE OTHER POINT IS AT THE SAME HEIGHT BUT IS OFF TO ONE SIDE (SAY AT HIS RIGHT SHOULDER). THE GEOMETRIC RELATIONSHIPS, AS WELL AS THE PHYSICAL DIMENSIONS, OF THIS SITUATION ARE SHOWN IN FIGURE 1.

NOW ASSUME THAT THE CAMERA HAS TAKEN A PICTURE OF THE SCENE IN FIGURE 1. THE FILM HAS NOW BEEN PROCESSED AND IS BEING PROJECTED UNDER TYPICAL PROJECTION CIRCUMSTANCES SUCH AS, FOR EXAMPLE, IN FIGURE 2. NOTE THAT SEVERAL CHANGES HAVE OCCURRED: (A) THE PROJECTION PLANE IS DIFFERENT FROM THE PLANE WHICH THE ORIGINAL SUBJECT OCCUPIED, (B) THE PROJECTION LENS IS DIFFERENT

THAN THE CAMERA LENS. REFLECTION WILL REVEAL THAT THESE TWO CIRCUMSTANCES ARE ALMOST INVARIABLY FOUND IN ACTUAL MOTION PICTURE PRACTICE (AND IN SLIDE PROJECTION, PHOTOGRAPHIC ENLARGEMENT AND PRINTING WORK, TOO). USING THESE OPERATING CONDITIONS LEADS TO PRODUCTION OF A REPRODUCED IMAGE WHICH IS IN SCALE BUT WHICH IS OUT OF SIZE. ACTUALLY, THE STUDY OF FIGURE 2 WILL SHOW THAT THERE ARE PREDICTABLE CHANGES IN THE BEHAVIOR OF ANY POINT IN SUCH AN OPTICALLY GENERATED DISPLAY. ANY OBJECT WHICH IS ABOVE OR BELOW THE OPTICAL AXIS IN THE ORIGINAL SCENE WILL BE LOCATED FURTHER ABOVE OR BELOW THE OPTICAL AXIS IF THE SCENE IS PROJECTED ONTO A PLANE MORE DISTANT THAN THAT OF THE ORIGINAL. IT WILL BE SEEN LESS FAR ABOVE OR BELOW THE OPTICAL AXIS IF THE SCENE IS PROJECTED ONTO A PLANE CLOSER THAN THAT OF THE ORIGINAL. THE EXAGGERATION OF PHYSICAL SIZE IS THE PARALLAX PHENOMENON.

THE SAME EFFECT OCCURS WITH ANY OBJECT APPEARING OFF TO THE SIDE OF THE OPTICAL AXIS. THUS, IN THE EXAMPLE BEING USED, THE RIGHT SHOULDER, IF PROJECTED ONTO A MORE DISTANT PLANE THAN THAT AT WHICH IT WAS PHOTOGRAPHED, WILL APPEAR FARTHER TO THE LEFT THAN IT WAS IN THE ORIGINAL SCENE. CONVERSELY, IF PROJECTED ONTO A PLANE CLOSER THAN THE ORIGINAL PHOTOGRAPHIC PLANE, THE HORIZONTAL DISTANCE IS MADE LESS THAN THE ORIGINAL.

THESE EFFECTS ARE WELL KNOWN AND HAVE BEEN CASUALLY OBSERVED BY PRACTICALLY EVERYONE WHO EVER LOOKED AT SLIDES OR MOVIES. FOR EXAMPLE, THE OPERATION OF THIS PRINCIPLE IS THE BASIS FOR SUCH EFFECTS AS OUT-OF-PROPORTION NOSES, HANDS, OR FEET IN SNAPSHOTS. THE GENERAL RULES CAN BE STATED: THE IMAGE OF AN OBJECT WHICH LIES ABOVE THE OPTICAL AXIS OF THE RECORDING SYSTEM WILL, IF

PROJECTED TO A PROJECTOR-SCREEN DISTANCE GREATER THAN THAT REPRESENTED BY THE OBJECT-CAMERA DISTANCE IN THE ORIGINAL PHOTOGRAPH, BE SEEN TO BE BOTH LARGER THAN ORIGINAL SIZE AND HIGHER ABOVE THE OPTICAL AXIS.³ THE PLACEMENT OF THE OBJECT BELOW THE OPTICAL AXIS AND SUBSEQUENT REPRODUCTION WILL RESULT IN THE OBJECT BEING BOTH LARGER AND LOWER IN RESPECT TO THE OPTICAL AXIS. WITHOUT LABORING THE POINT FURTHER, IT MAY BE OBSERVED THAT THE OPTICAL AXIS IS THE POINT AROUND WHICH THE IMAGE CHANGES TAKE PLACE AND⁴ THAT THEY TAKE PLACE ALONG ALL MERIDIANS.

QUITE OBVIOUSLY, PARTS OF THE HUMAN ARE SITUATED IN SEVERAL DIFFERENT PLANES EVEN WHEN HE IS PERFECTLY STATIONARY. WHEN HE ENGAGES IN VIOLENT MANEUVERS, HE OCCUPIES EVEN MORE PLANES. FROM WHAT HAS BEEN SHOWN, IT IS EASY TO SEE HOW IT HAS BEEN IMPOSSIBLE FOR PHOTOGRAMMETRIC TECHNIQUES TO BE SUCCESSFULLY APPLIED. STILL, THE NECESSARY INGREDIENT WHICH WOULD BE NEEDED TO PERMIT PHOTOGRAMMETRIC MEASUREMENT OF DIMENSIONS IS PRESENT IN THE PHOTOGRAPHIC SITUATION AND HAS BEEN MENTIONED ABOVE. IT HAS BEEN NOTED THAT ANY PROJECTION TO ANOTHER PLANE MORE DISTANT OR MORE CLOSE WILL MAKE EITHER A LARGER OR SMALLER IMAGE. IF ONE WOULD INCORPORATE INTO THE ORIGINAL PHOTOGRAPH A KNOWN REFERENT AND THEN WOULD SO ARRANGE THE PROJECTION THAT THE

3. FOR PURPOSES OF THE PRESENT DISCUSSION, IT IS ASSUMED THAT THE CAMERA AND PROJECTOR LENSES ARE MATCHED. IN THE CASE WHERE THEY ARE NOT, THE ALTERATION IS RECOGNIZABLE AND CAN BE COMPENSATED FOR BY RELATIVELY SIMPLE CONVERSION MATHEMATICS.

4. SOPHISTICATED READERS WILL RECOGNIZE THAT THE GEOMETRY INVOLVED HERE WILL COVER THE COMMENTS MADE IN GIBSON'S DISCUSSION OF VISUAL PERCEPTION ON CREATION OF VISUAL PERSPECTIVE AND APPARENT MOTION. ALSO, THE ANIP AND IMHEP PROGRAM OF AIRCRAFT INSTRUMENTATION MAKE USE OF THIS LOGIC IN COMPUTATION OF THE "IMPACT POINT" ALONG WHICH AN AIRFRAME IS BEING MOVED.

REFERENCE OBJECT IS RESTORED TO ACTUAL SIZE,⁵ IT WOULD BE DISCOVERED THAT SEVERAL VALUABLE CONSEQUENCES RESULT. FOR ONE, THERE WILL BE NO VERTICAL OR HORIZONTAL PARALLAX IN THE PROJECTED IMAGE AT THE POINT WHICH IS USED AS THE REFERENCE. (OBJECTS ON OTHER PLANES WILL HAVE PARALLAX.) FOR ANOTHER THING, THE DISTANCE BETWEEN THE PROJECTOR AND THE PROJECTION SCREEN WILL BE EXACTLY THE SAME DISTANCE AS THE DISTANCE BETWEEN THE CAMERA AND THE REFERENCE OBJECT IN THE ORIGINAL SCENE. THEREFORE, ALL THAT IS NEEDED TO RECREATE THE COORDINATES IN SPACE OF THE ORIGINAL REFERENCE OBJECT IS TO ADJUST THE DISTANCE BETWEEN THE PROJECTION SCREEN AND THE PROJECTOR SO THAT A STANDARD SIZED REFERENCE IS RESTORED IN CORRECT SIZE. AT THAT POINT, ONE NEEDS ONLY TO MEASURE UP AND OVER FROM THE OPTICAL AXIS TO THE REFERENCE POINT TO GET THE VERTICAL AND HORIZONTAL COORDINATES AND MEASURE FROM SCREEN TO PROJECTOR TO GET THE LONGITUDINAL COORDINATE. VERY SIMPLE, INDEED!

REFERENCE TO FIGURE 3 WILL NOT ONLY SHOW THE WAY IN WHICH THE METHOD WORKS, BUT ALSO WILL CONFIRM THE SIMPLICITY AND DIRECTNESS OF THIS TECHNIQUE. BY THE PRACTICAL EXPEDIENT OF ATTACHING A SMALL SPHERE TO THE MAN OR HIS WORK-SPACE AT EVERY POINT IN WHICH THERE IS AN INTEREST, ONE CAN CATCH ALL THE TRIDIMENSIONAL SPACE COORDINATES IN ONE SINGLE PHOTOGRAPH TAKEN FROM A SINGLE CAMERA. IF BODY PARTS ARE IN DIFFERENT PLANES, AS IN FIGURE 4, ONE NEED

5. READERS WHO ARE FAMILIAR WITH FIRE CONTROL PRACTICES WILL RECOGNIZE THAT THIS IS THE PRINCIPLE USED IN STADIA RANGING. THE SAME PRACTICE IS USED IN PHOTOINTERPRETATION AND PHOTOGRAPHIC MAP WORK.

MERELY ADJUST THE IMAGE SIZES FOR EACH PLANE, ONE BY ONE, EACH TIME READING OUT THE COORDINATES. IN THIS WAY, ONE CAN VERY CLOSELY IDENTIFY WHERE ALL OF THE MAN'S EXTREMITIES WERE AT A GIVEN INSTANT. IT IS AN OBVIOUS STEP TO MOVE NEXT TO MOTION PICTURE PHOTOGRAPHY. IN THIS WAY, THE SEQUENCE OF STILL SHOTS CAN BE CUMULATED TO RECONSTRUCT THE FOURTH DIMENSION OF THE MOTION ENVELOPE: TIME.

APPLICATION OF THIS METHODOLOGY ALLOWS THE SUCCESSFUL MEASUREMENT OF MOTION AND DIMENSIONS IN PRACTICALLY ANY ACTIVITY WHICH CAN BE PHOTOGRAPHED REASONABLY SATISFACTORILY.

A WORD IS IN ORDER AT THIS POINT ON THE CHARACTERISTICS REQUIRED OF THE REFERENCE OBJECT. FIRST (AND MANDATORY, AS WELL) IS THAT THE REFERENCE BE A SPHERE. ANY TWO DIMENSIONAL OBJECT OR MARK WILL UNDERGO FORESHORTENING IN OBLIQUE VIEWS. THIS FORESHORTENING WOULD PROHIBIT ACCURATE REPLICATION OF REFERENCE SIZE. SECONDARY CHARACTERISTICS INCLUDE: SUITABILITY FOR PHOTOGRAPHIC RECORDING, SMALL SIZE AND LIGHT WEIGHT SO AS NOT TO IMPEDE ACTIVITY OF THE SUBJECT, AND EASE OF ATTACHMENT AND REMOVAL. AS WILL BE REVEALED IN THE APPARATUS AND PROCEDURES SECTION OF THIS REPORT, EXCELLENT SUCCESS HAS BEEN OBTAINED WITH PING PONG BALLS ATTACHED WITH LIGHT ELASTIC BANDS OR PINNED ONTO CLOTHING. IN SUMMARY, A METHOD HAS BEEN DEVISED AND TESTED WHICH ACCOMPLISHES THE DIRECT READOUT OF FOUR-DIMENSIONAL COORDINATES OF COMPLEX MOTIONS.

SECTION THREE

APPARATUS AND PROCEDURES

A. TASK SUPPORT EQUIPMENT

TWO OPEN-FACED STEEL RACKS, EACH OF WHICH WAS 76 INCHES HIGH, 36 INCHES WIDE, AND 12 INCHES DEEP, WERE USED AS PROPS FOR THE TASKS. SHELVES WERE SET TO 10 INCHES AND 60 INCHES FROM THE FLOOR. TO SIMULATE EQUIPMENT WHICH THE MEN MIGHT NORMALLY HANDLE ON DUTY, FOUR 18 1/2 X 12 X 5 INCH WOODEN BOXES WERE OBTAINED AND FILLED TO THE WEIGHT OF 32 POUNDS. THIS WEIGHT IS APPROXIMATELY THE MAXIMUM WEIGHT ONE MIGHT EXPECT TO FIND IN USE FOR CONTINUOUS CARRYING AND LIFTING TO A 60 INCH HEIGHT. A 1/4 INCH THICK PLYWOOD SHEET WAS USED TO CREATE A SIMULATED DESK OR TABLE TOP IN THE "CHANGE PLACES" TASK (SEE LATER). IT WAS CANTILEVERED OUT 18 INCHES FROM A SHELF OF ONE OF THE STEEL RACKS. THE TOP SURFACE OF THE SHELF WAS PLACED AT A HEIGHT OF 29 1/2 INCHES ABOVE THE FLOOR. THIS SET-UP ASSURED A CLEAR VIEW OF THE SUBJECT'S FEET AND KNEES BENEATH THE TABLE TOP. A STANDARD SWIVEL OFFICE CHAIR WITH CASTERS AND ARMS WAS UTILIZED IN ONE TASK. THE SEAT REFERENCE POINT WHERE THE BACK INTERSECTS THE SEAT PAN WAS LOCATED 18 INCHES FROM THE FLOOR.

EACH SUBJECT PERFORMING IN EACH TASK WORE A NUMBER OF PING PONG BALLS ATTACHED TO HIS CLOTHING AND BODY EITHER BY LIGHT ELASTIC BANDS OR SAFETY PINS. ONE WAS LOCATED ON THE TOP OF HIS HEAD, ONE OVER EACH SHOULDER-ARM JOINT, ONE JUST ABOVE THE OUTSIDE OF EACH ELBOW, ONE LOW ON THE OUTSIDE OF EACH WRIST, ONE HIGH ON THE OUTSIDE OF EACH THIGH, ONE SUSPENDED 5 INCHES

BELOW HIS BELT IN THE MIDDLE OF HIS BACK, ONE JUST BELOW THE OUTSIDE OF EACH KNEE, AND TWO ON EACH FOOT---ONE TO THE FRONT AND ONE TO THE REAR OF EACH ANKLE. THE LOGIC WAS TO PROVIDE A REFERENCE POINT AS NEAR AS POSSIBLE TO EACH POINT ON THE BODY WHICH MIGHT CONSTITUTE A TANGENT TO THE ENVELOPE OF SPACE AS THE MAN MOVED ABOUT.

B. PHOTOGRAPHIC EQUIPMENT

A 16 MM BOLEX H/6 SUPREME MOTION PICTURE CAMERA WITH A 10 MM SWITAR LENS WAS USED FOR ALL TASK RECORDING PURPOSES. THE CAMERA WAS FASTENED TO AN IMMOVABLE TRIPOD-LIKE MOUNT DURING PICTURE TAKING, SO THAT THE CENTER OF THE LENS (OPTICAL AXIS) WAS $36 \frac{3}{4}$ INCHES OFF THE FLOOR AND THE FILM PLANE 20 FEET FROM A REFERENCE BACKDROP. KODAK TRI-X REVERSAL BLACK AND WHITE FILM WAS USED EXCLUSIVELY THROUGHOUT THE TASK RECORDINGS. FOUR FLOOD-LIGHTS WERE FASTENED ON THE CAMERA MOUNT, TWO ON EACH SIDE OF THE CAMERA. THE LENS WAS TESTED AND FOUND TO PRODUCE A GOOD OPTICALLY FLAT IMAGE WHICH WAS SUFFICIENTLY FREE FROM DISTORTION AS TO PERMIT USE FOR THE INTENDED PURPOSE. AN 8 X 8 FOOT SCREEN OF MASONITE SUPPORTED BY 2 X 2 INCH LUMBER WAS CENTRALLY PLACED BEHIND EACH TASK AREA TO FORM A PHOTOGRAPHIC BACKDROP. THE ROUGH SIDE OF THE MASONITE FACED OUT AND WAS PAINTED A FLAT BLACK TO MINIMIZE REFLECTIONS. A $1/4$ INCH DIAMETER WHITE CORD STRETCHED OUT HORIZONTALLY ACROSS THE BACKDROP AT A HEIGHT OF $36 \frac{3}{4}$ INCHES (EQUAL TO THE CAMERA LENS IN HEIGHT). ANOTHER CORD BISECTED THE BACKDROP VERTICALLY. THE INTERSECTION OF THESE CORDS WAS MADE TO COINCIDE PRECISELY WITH THE

THE OPTICAL AXIS OF THE CAMERA.⁶ THE BACKDROP WAS MADE TO BE PERFECTLY PERPENDICULAR TO THE OPTICAL AXIS. ACCORDINGLY, THE BACKDROP AND FILM PLANE WERE COMPLETELY PARALLEL.

C. DATA REDUCTION EQUIPMENT

THE 16 MM PROJECTOR USED IN DATA REDUCTION WAS A BELL AND HOWELL MODEL 173 TIME AND MOTION STUDY PROJECTOR, WITH REVERSE, HAND CRANK, AND STOP-FRAME CAPACITY. IT WAS EQUIPPED WITH A $5/8$ INCH FOCAL LENGTH (WIDE ANGLE) LENS. AS HAS BEEN SHOWN IN THE PRECEDING SECTION, THE USE OF THIS TECHNIQUE REQUIRES THAT EITHER THE SCREEN OR THE PROJECTOR BE MOBILE. IT IS MUCH EASIER TO MOVE A PROJECTOR. ACCORDINGLY, THE PROJECTOR WAS AFFIXED TO A MOVABLE DOLLY WHICH RAN ON A TRACK PERFECTLY PERPENDICULAR TO THE PROJECTION SURFACE. (THE SAME DOLLY SERVED AS CAMERA AND FLOODLIGHT MOUNT DURING THE DATA ACQUISITION STAGE. WHEN USED AS A CAMERA PLATFORM, IT HAD A REMOVABLE $1\ 1/2$ INCH ANGLE ALUMINUM TRIPOD-LIKE SUPERSTRUCTURE.) THE DOLLY BASE WAS A 3 FOOT SQUARE PIECE OF $3/4$ INCH PLYWOOD. ON THE BASE WERE ATTACHED V-GROOVED 7 INCH WHEELS. THE TRACK ON WHICH THE WHEELS RAN WAS MADE OF $1\ 1/2$ INCH ANGLE ALUMINUM LAID IN TWO PARALLEL RAILS, 32 INCHES ON CENTER. THE TRACK BED WAS MADE IN SECTIONS OF PLYWOOD WHICH COULD BE FIRMLY FASTENED TOGETHER BY LOOSE-PIN HINGES OR USED INDIVIDUALLY IF NECESSARY.

6. PRACTICALLY SPEAKING, IT WAS FOUND THAT OCCASIONALLY THERE WAS DIFFICULTY IN MEASURING THE SUBJECT'S LOCATION DUE TO OCCLUSION OF THIS CENTRAL INTERSECTION BY HIS BODY. HENCE, THE BACKBOARD WAS RIMMED BY NAILS AT ONE INCH INTERVALS. WHITE CORD WAS STRUNG ON CERTAIN OF THE NAILS TO PRODUCE AN ACCURATE GRID WHEN NEEDED. CAREFUL EXTRAPOLATION FROM A KNOWN VISIBLE LINE IN THE GRID PERMITTED EXACT LOCATION OF THE INVISIBLE BUT VITAL CENTER INTERSECTION OF THE OPTICAL AXIS.

ALONGSIDE ONE RAIL OF THE TRACK WAS MADE A SET OF INDEX NUMBERS REPRESENTING THE DISTANCE FROM BACKBOARD TO OBJECT. THESE NUMBERS WERE NOT TRUE INCHES. INSTEAD, THEY FOLLOWED A RATIO DETERMINED BY THE RELATIONSHIP BETWEEN THE CAMERA LENS AND PROJECTION LENS. THIS STRIP WAS LAID OUT WITH $1/4$ INCH SCALE MARKS. A RECORDER ASSISTED BY TAKING DOWN MEASUREMENTS OF VERTICAL AND HORIZONTAL COORDINATES WHICH WERE READ OFF BY THE MAN AT THE SCREEN. AT THE SAME TIME, THE RECORDER FOLLOWED THE PROJECTOR BACK AND FORTH TO PICK UP THE LONGITUDINAL MEASURES. ACTUALLY, THE RECORDER DID NOT HAVE TO MOVE VERY FAR. THE ACTUAL SCALES USED WERE CUT TO HALF-SIZE BY THE SIMPLE EXPEDIENT OF CAUSING EVERYTHING TO BE PROJECTED HALF-SIZE AND USING A HALF-SIZED REFERENCE OBJECT SCALE ON THE RULER (SEE LATER).

THERE IS NO REASON WHY THE PROJECTED IMAGES HAVE TO BE FULL SIZE. THEY COULD BE $+2X$, $-4X$, $+1/4X$, OR ANY OTHER SCALE WHICH IS CONVENIENT. THE ONLY REQUIREMENT IS THAT ALL MEASURING SCALES USED IN DATA REDUCTION MUST BE IN THE SAME SCALE. WITH THE SIZE IMAGES WHICH OUR DATA CREATED, IT SUITED OUR PURPOSES BEST TO WORK AT $-1/2X$ REDUCTION. THE RECORDER PICKED OFF LONGITUDINAL DISTANCE BY OBSERVING A POINTER WHICH EXTENDED FROM THE DOLLY DOWN TO THE INDEX ON THE TRACK. ELECTRICAL SERVICE TO THE PROJECTOR WAS PROVIDED BY A TRAILING EXTENSION CORD LEADING IN TO THE DOLLY ON AN OUTRIGGER WHICH KEPT THE WIRE CLEAR OF THE TRACK.

TO FACILITATE DATA REDUCTION, AN ESPECIALLY MADE "RULER" WAS USED TO MEASURE THE DIMENSIONS OF THE PROJECTED IMAGE. THE "RULER" CONSISTED OF A SHEET OF BRISTOL BOARD, 20 X 26 INCHES, WHICH HAD INCHES MARKED OFF IN THE PROPER

STANDARD SCALE ON ALL FOUR SIDES AND ZERO POINTS AT ALL FOUR CORNERS. EACH CORNER HAD A BLACK DISK THE SIZE OF THE PROPER STANDARD RATIO OF THE DIAMETER OF A PING PONG BALL (HALF-SIZE). THEREFORE, EACH SIDE HAD TWO SETS OF NUMBERS EXTENDING IN OPPOSITE DIRECTIONS. EACH CORNER POINT HAD A ZERO POINT WITH CALIBRATIONS EXTENDING ON BOTH THE X AND Y AXES AWAY FROM IT (SEE FIGURE 5). OBVIOUSLY, BY RULING THE "RULER" WITH FOUR ZERO CORNERS, IT IS POSSIBLE TO READ THE COORDINATES IMMEDIATELY IN ANY QUADRANT WHERE THE REFERENCE MAY FALL.

THE "RULER" WAS USED BY VARYING THE SIZE OF THE PROJECTED IMAGE OF A GIVEN PING PONG BALL WHICH WAS FASTENED ON THE SUBJECT UNTIL IT JUST FILLED THE BLACK DISK AT THE CORNER OF THE "RULER". IT WAS ASSURED THAT THE "RULER" WAS SQUARE ON THE SCREEN WITH THE PHOTOGRAPHIC GRID AND THAT THE ZERO POINT OF THE CORNER WAS AT THE RIGHT POINT ON THE IMAGE OF THE BODY. THE POINT AT WHICH THE HORIZONTAL AND VERTICAL REFERENCE LINES, WHICH WERE ORIGINALLY PHOTOGRAPHED WITH THE SUBJECT, INTERSECTED THE "RULER" COULD THEN BE NOTED. (SEE FIGURE 6 FOR USE OF THE "RULER".) UNDER THESE CIRCUMSTANCES, THE OBJECT WILL HAVE BEEN RECONSTITUTED IN EXACT TRIDIMENSIONAL COORDINATES AND CAN BE MEASURED DIRECTLY ON THE "RULER" AND THE TRACK INDEX.

FOR THE Y AXIS, THE MEASURER CALLED OUT THE DISTANCE ABOVE (+) OR BELOW (-) THE 36 3/4 INCH HIGH CORD ON THE BACKBOARD AT WHICH THE POINT LAY. FOR THE X AXIS, HE WOULD CALL OUT THE DISTANCE THE POINT LAY EITHER TO THE LEFT (+) OR THE RIGHT (-) OF THE VERTICAL X AXIS CORD ON THE BACKBOARD.

FIGURE 5

DATA REDUCTION TEMPLATE

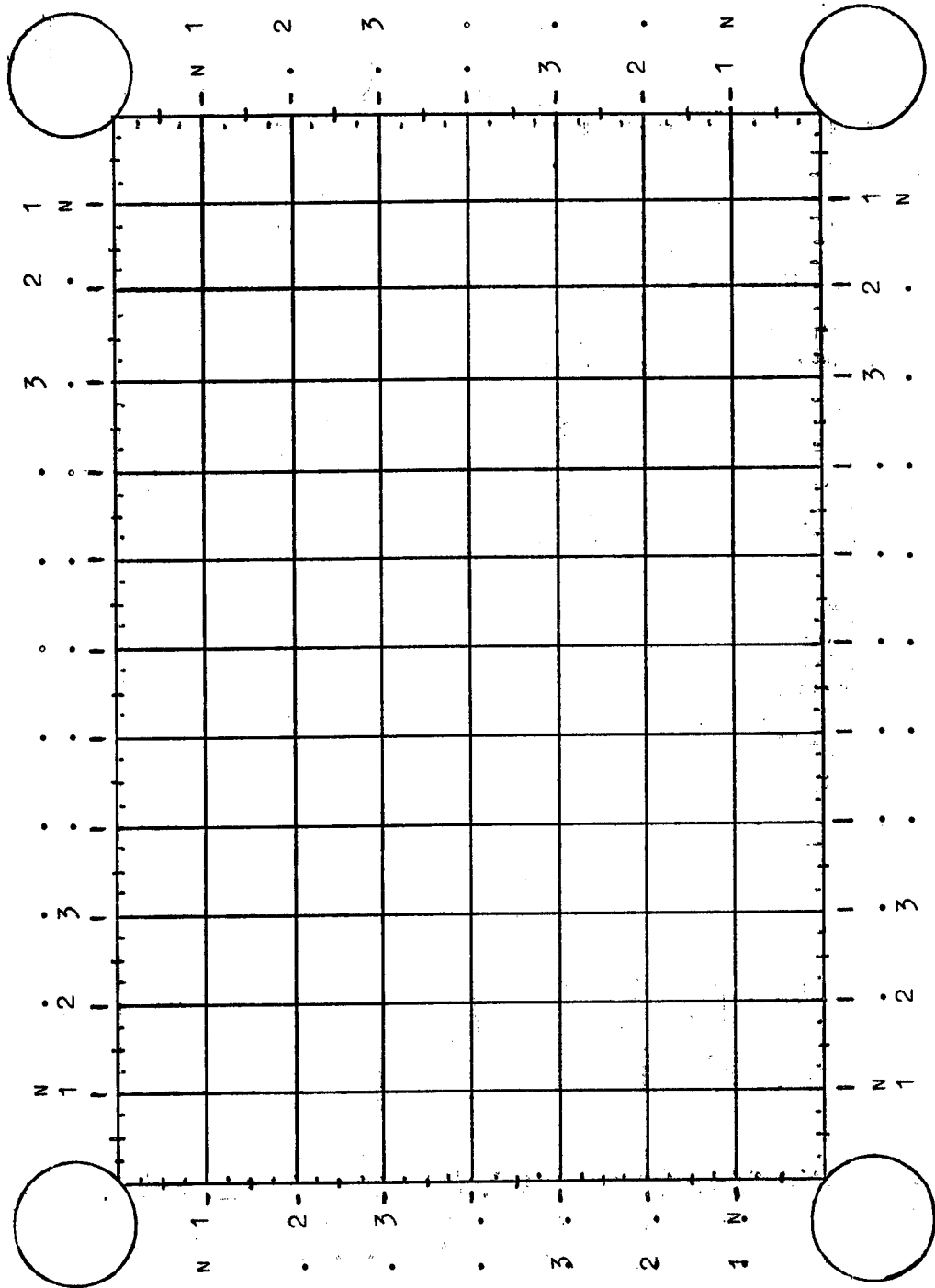
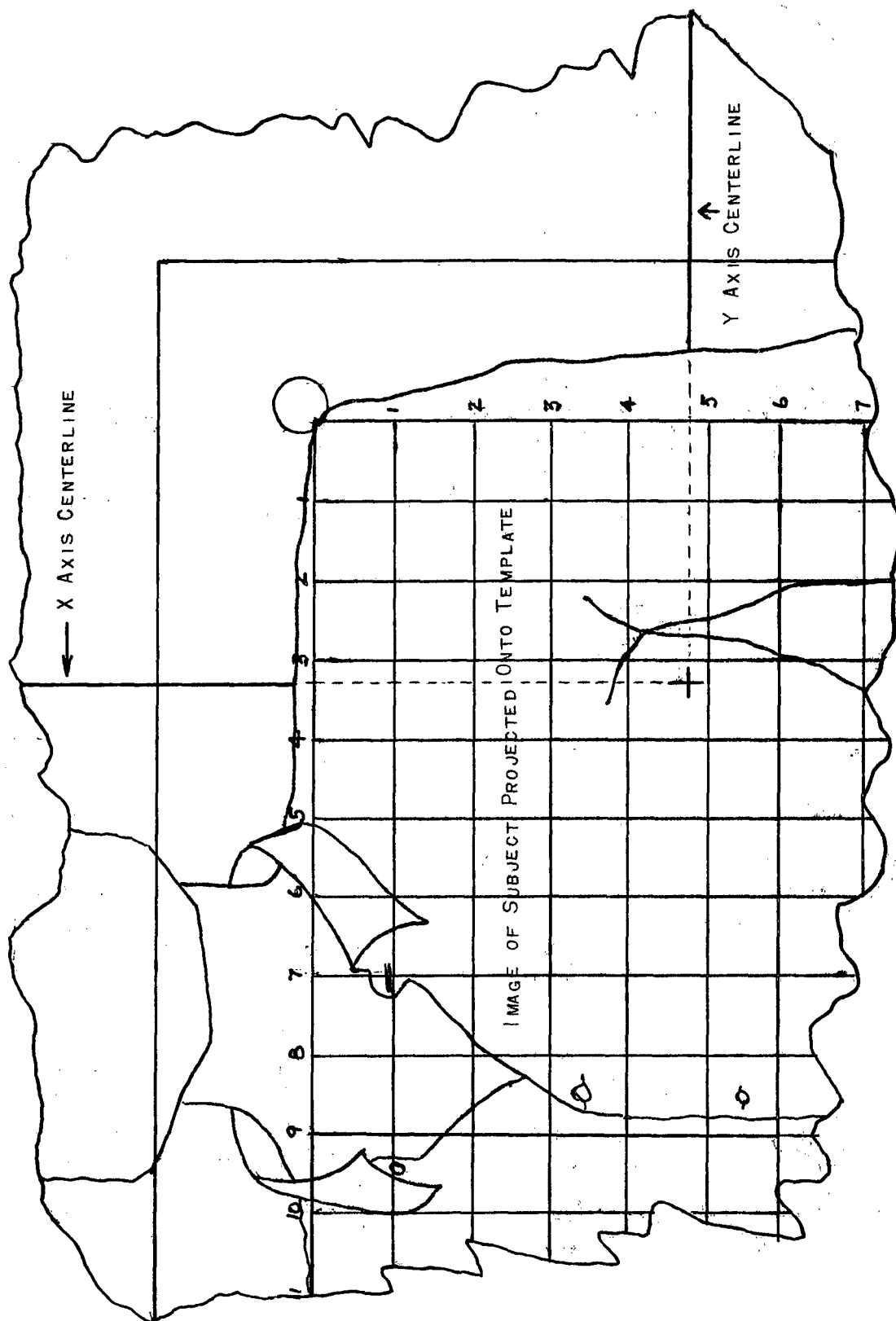


FIGURE 6

DATA REDUCTION TECHNIQUE



THE RECORDER CONVERTED THE Y AXIS MEASUREMENT TO TRUE HEIGHT BY ADDING OR SUBTRACTING $36 \frac{3}{4}$ INCHES BEFORE RECORDING IT, AND MERELY RECORDED VERBATIM THE X AXIS COORDINATE.

A TIGHTLY SPRUNG CORD WAS PASSED THROUGH A PULLEY AT EACH END OF THE TRACK, FORMED INTO AN ENDLESS LOOP, AND THEN ATTACHED TO THE DOLLY. THIS WAS USED BY THE MAN AT THE SCREEN TO POSITION THE PROJECTOR AT THE RIGHT DISTANCE TO MAKE A BODY PART STANDARD SIZED. BY STANDING AT THE PROJECTION SCREEN AND PULLING ONE WAY OR THE OTHER ON THIS ENDLESS LOOP OF CORD, THE DOLLY COULD BE MADE TO RUN BACK AND FORTH ON THE TRACK. IN THIS WAY, THE SIZE OF THE PROJECTED IMAGE COULD EASILY BE CONTROLLED RIGHT AT THE SCREEN BY THE PERSON MATCHING THE IMAGE SIZES.

D. MEASUREMENT POINTS

WHEN THE SUBJECT IS FULLY CLOTHED AND MOVING ABOUT, HE BECOMES A DIFFICULT SUBJECT FOR ANTHROPOMETRY. HIS CLOTHING FLAPS, HIS HAIR STICKS UP, HIS SKIN AND MUSCLES SLIDE AROUND ON HIS SKELETON, AND, SPEAKING GENERALLY, ALL THE NICETIES OF ANTHROPOMETRIC BODY REFERENCE POINTS BECOME UNSTABLE. THEREFORE, IT HAS BEEN NECESSARY TO ADOPT CERTAIN MORE OR LESS ARBITRARY RULES FOR MEASURING.

BASICALLY, THE PURPOSE FOR WHICH THE PRESENT METHODOLOGY IS DEVISED IS THE MEASUREMENT OF THE SPACE OCCUPIED BY REAL PEOPLE DOING REAL TASKS WHILE REALISTICALLY OUTFITTED FOR THE TASK. IT WOULD SEEM FITTING THAT AN EQUALLY EMPIRICAL DEFINITION BE ADOPTED FOR WHAT WILL BE MEASURED. IT HAS BEEN THE PRACTICE HEREIN TO SAY THAT THE INTEREST LIES IN THE OBJECT

WHICH CREATES THE BOUNDARY OF SPACE OCCUPIED IN THE TASK. THIS MEANS MEASURES MUST BE TAKEN WHEREVER MAXIMUM DIMENSIONS ARE OBTAINED, WHETHER IT IS ON SKIN, CLOTH, LEATHER OR HAIR. THE FOLLOWING POINTS WERE USED:

(1) HEAD - TOP, CENTER, AT WHEREVER THE HAIR STICKS UP TO; (2) SHOULDER - ON THE CLOTHING AT THE POINT OF MAXIMUM INFLECTION BETWEEN HORIZONTAL LINE OF SHOULDER AND VERTICAL LINE OF THE ARM (IF THE ARM WAS STRAIGHT OUT OR POINTING UP, THEN AN APPROXIMATION WAS MADE FOR THE PROBABLE WHEREABOUTS OF THE ACROMION); (3) ELBOW - ON THE CLOTHING AS NEARLY AS POSSIBLE TO THE POINT OF MAXIMUM PROTRUSION (GENERALLY CLOSE TO THE EPICONDYLE OF THE HUMERUS); (4) BUTTOCKS - ON THE CLOTHING AT THE POINT OF MAXIMUM EXTENT AFT ON THE RUMP; (5) KNEE - DEPENDING UPON ORIENTATION IN PICTURE, EITHER ON THE CLOTHING AT SIDE OF KNEE (APPROXIMATELY HORIZONTALLY OUT FROM THE KNEECAP OR ABOVE THE EPICONDYLE OF THE FIBULA) OR, IF SEEN FROM THE SIDE, ON THE CLOTHING AT ABOUT THE KNEECAP OR THE POPLITEAL SPACE; (6) HAND - INTERSECTION OF THE HAND AND THE LITTLE FINGER, ON THE SKIN; (7) FOOT - ON THE SHOE SOLE AS NEAR AS POSSIBLE TO THE PROBABLE WHEREABOUTS OF THE LITTLE TOE OR THE WIDEST PART OF THE SHOE; (8) HIP - ON THE CLOTHING AT WIDEST POINT OF HIP, GENERALLY AT ABOUT THE TROUSER'S POCKET OPENING.

THE SUBJECTS WERE FULLY CLOTHED. ALL WORE SPORT SHIRTS OR KHAKI UNIFORM SHIRTS WITH COLLARS OPEN, SLACKS OR KHAKI UNIFORM TROUSERS, AND OXFORD-TYPE SHOES. NO UNUSUAL FEATURES WERE OBSERVED IN THE APPAREL WHICH WOULD MAKE THEM DIFFERENT FROM USUAL NAVY DUNGAREES OR LIGHT WORK CLOTHING IN GENERAL.

E. TASKS

THE TASKS WHICH WERE PHOTOGRAPHED IN THIS RESEARCH WERE SELECTED FOR TWO PURPOSES. FIRST, THEY WERE TASKS WHICH WOULD PROVIDE REASONABLE OPPORTUNITY FOR CAPABILITIES AND LIMITATIONS OF THE METHODOLOGY TO BECOME APPARENT. IN THIS WAY, THE SUITABILITY OF THE METHOD WOULD BE TESTED. SECOND, THE TASKS WERE TO BE REALISTIC REPRESENTATIONS OF THE WORK WHICH IS DONE EVERY DAY BY ORDINARY PEOPLE IN A VARIETY OF SITUATIONS. THUS, EVEN THOUGH OBTAINED IN A LABORATORY SETTING AND USING PROPS WHICH ARE NOT COMPLETELY LIKE REAL JOBS, THE LIMITED DATA WHICH WAS OBTAINED WOULD HAVE PRACTICAL UTILITY.

THERE IS A STRONG TENDENCY FOR PHOTOGRAPHIC SUBJECTS TO DEVIATE FROM THEIR NORMAL BEHAVIOR AS SOON AS THEY GET "ON CAMERA". IF ALLOWED TO CONTINUE UNCHECKED, THIS TENDENCY COULD RUIN THE DATA. THEREFORE, THE EXPERIMENTERS WERE AT GREAT PAINS TO USE ALL EFFORTS TO BRING ABOUT NORMAL BEHAVIOR FREE OF TENSION AND FREE OF HAM ACTING. IN ACTUAL PRACTICE, IN ALL OF THE TASKS, THE EXPERIMENTERS DELIBERATELY CONFOUNDED THE EXPECTATIONS OF THE SUBJECTS BY TURNING ON LIGHTS AND RUNNING THE CAMERA AT TIMES AS IF RECORDS WERE BEING MADE WHEN, IN REALITY, THEY WERE NOT. FURTHERMORE, SOME FILMS WERE MADE, OSTENSIBLY FOR THE RECORD, WHICH WERE NOT IN FACT ANALYZED. AFTER A FEW MINUTES OF OPERATION UNDER THESE CONDITIONS, THE SUBJECTS SEEMINGLY RELAXED, BEHAVED PRETTY MUCH AS THEIR NATURAL SELVES, AND STOPPED TRYING TO BEAT THE PROBLEM OR BECOME MOVIE STARS.

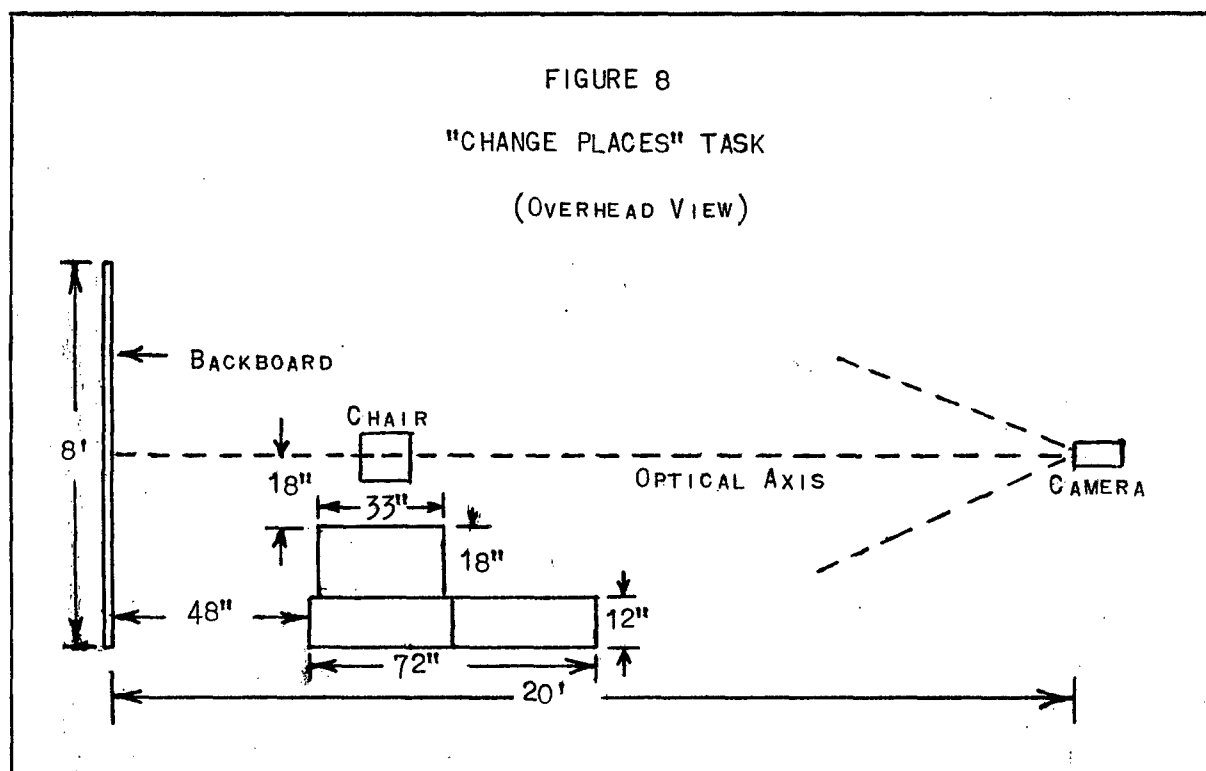
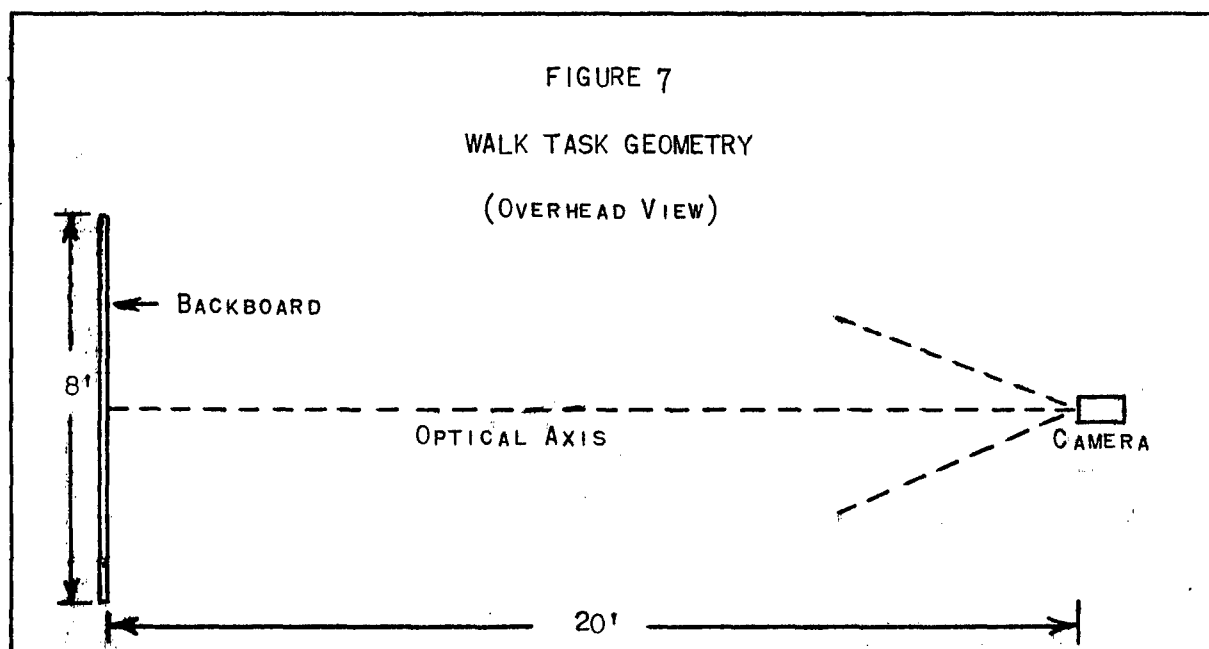
TASK A - "WALK" TASK

THIS TASK UNDERTOOK TO EXAMINE THE ENVELOPE OF SPACE CIRCUMSCRIBED BY A SIMPLE STRAIGHT WALK. EACH SUBJECT STARTED FROM A BACKDROP LOCATED 20 FEET FROM THE FILM PLANE AND WALKED DIRECTLY TOWARD THE CAMERA. WHEN APPROXIMATELY 5 FEET FROM THE CAMERA, HE TURNED OFF ABRUPTLY, WHEREUPON THE RECORDING WAS TERMINATED. SUBJECTS WERE INSTRUCTED TO WALK AT THEIR NORMAL SPEED, USING THEIR REGULAR GAIT. SEVERAL PRACTICE TRIALS AND FAKE TRIALS WERE HELD BEFORE AND AFTER THE TRIAL FOR RECORD IN ORDER THAT A SUBJECT WOULD TEND TO WALK NORMALLY AND AT EASE. THE GEOMETRY OF THE TASK IS SHOWN IN FIGURE 7.

TASK B - "CHANGE PLACES" TASK

THIS TASK REQUIRED TWO SUBJECTS TO SUCCESSIVELY REPLACE EACH OTHER AT A SEATED DUTY STATION. THIS IS A TYPE OF ACTIVITY WHICH IS WIDELY ENCOUNTERED AS ONE PERSON RELIEVES ANOTHER OF DUTY AT A SEATED WORKSPACE. AS A TWO MAN TASK, IT DEMONSTRATES THE ABILITY OF THE TECHNIQUE TO MEASURE THE INTERACTIONS BETWEEN PEOPLE IN JOINT ACTIVITIES. ALSO, WHEN VIEWED INDIVIDUALLY, THE INDIVIDUAL ACTIONS OF SITTING DOWN, STANDING UP, STARTING TO WALK, AND SO FORTH CAN BE PULLED OUT OF EACH PERSON'S OWN ACTIVITIES.

AS THE TASK STARTS, ONE MAN (MAN A) IS SEEN WITH HIS HANDS UPON A TABLE TOP WHILE HE IS SEATED ON A CONVENTIONAL DESK CHAIR (APPARATUS DESCRIBED EARLIER). ANOTHER MAN (MAN B) IS OFF CAMERA. AT THE START OF THE TASK, MAN B WALKS UP TO THE RIGHT OF MAN A. MAN A, SEEING THAT HIS REPLACEMENT HAS "ARRIVED FOR DUTY", PUSHES BACK HIS CHAIR, RISES, AND WALKS AWAY TO



THE LEFT. WHEN THE CHAIR BECOMES AVAILABLE, MAN B. ACQUIRES IT, SITS DOWN ON IT, MOVES IN TO THE TABLE, AND PLACES HIS HANDS UPON THE TABLE AS IF WRITING OR OPERATING CONTROLS. MEANWHILE, MAN A HAS DOUBLED BACK BY WALKING AROUND BEHIND THE APPARATUS SO THAT HE NOW APPEARS AT MAN B'S RIGHT SIDE. MAN B RECOGNIZES MAN A'S RETURN SO HE RELINQUISHES THE CHAIR AND LEAVES THE DUTY STATION TO MAN A. MAN A SEATS HIMSELF AND PROCEEDS TO SIMULATE WORK UNTIL MAN B SHOWS UP AGAIN. A COMPLETE FILMING CYCLE WAS RECORDED FOR EACH MAN REPLACING THE OTHER THREE TIMES. ADEQUATE BRIEFING, PRACTICE, AND FAKE TRIALS WERE PROVIDED. THE TASK GEOMETRY IS SHOWN IN FIGURE 8.

TASK C - "EQUIPMENT TRANSFER" TASK (ONE MAN)

THIS TASK INVOLVES GETTING, TRANSPORTING, AND PLACING A BULKY, HEAVY OBJECT ON SHELVES OR RACKS. IT IS A TASK WHICH IS WIDESPREAD IN THE WORKING WORLD---SERVICE ON ELECTRONIC RACKS, STORAGE OF SUPPLIES, AND EQUIPMENT SET-UP, TO MENTION A FEW. TWO IDENTICAL RACKS, EACH OF WHICH WAS 3 FEET WIDE, WERE LINED UP 4 FEET APART, FACING THE SAME DIRECTION. THERE WAS A LOW SHELF (10 INCHES ABOVE THE FLOOR) AND A HIGH SHELF (60 INCHES ABOVE THE FLOOR). BEFORE THE TASK WAS STARTED, THE SHELVES WERE PRE-LOADED. THREE WEIGHTED BOXES (DESCRIBED EARLIER) WERE PUT ON THE SHELVES WITH ONE SPACE (TOP RIGHT WHEN FACING SHELVES) REMAINING OPEN. THE SUBJECT'S TASK WAS TO CARRY A BOX FROM LEFT HIGH SHELF TO THE EMPTY SPACE OPEN ON THE RIGHT HIGH SHELF. HE THEN SQUATTED DOWN, OBTAINED A BOX FROM THE LOWER RIGHT SHELF, AND CARRIED IT TO THE OPEN SPACE ON THE SHELF AT THE UPPER LEFT. THEN, SQUATTING AGAIN, HE GOT THE LOWER LEFT BOX AND TRANSPORTED

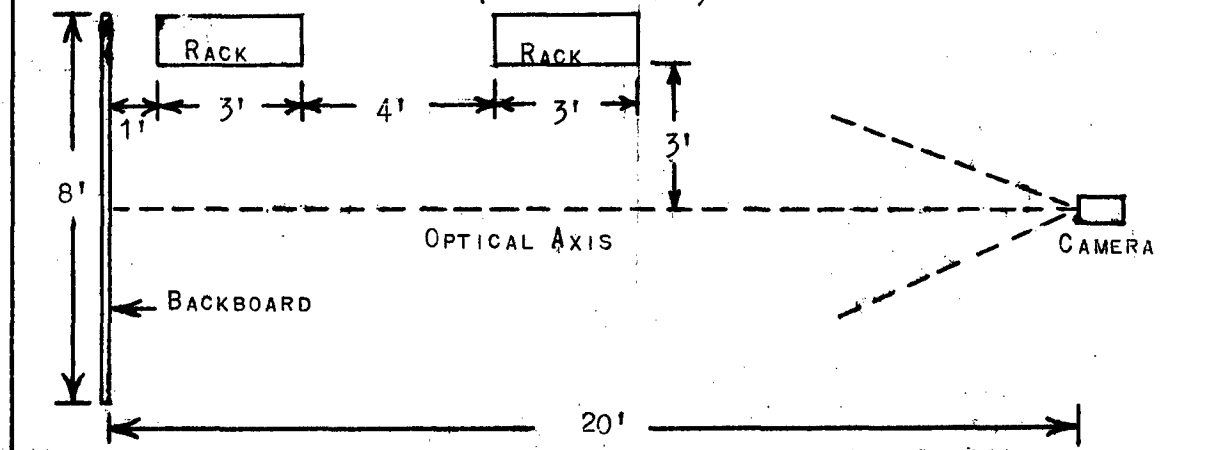
IT TO THE LOWER RIGHT SHELF SPACE. RISING STRAIGHT UP, HE GOT THE BOX ON THE UPPER RIGHT AND CARRIED IT ACROSS AND DOWN TO THE LOWER LEFT. UPON PUTTING THAT BOX AWAY, HE ROSE TO GET THE BOX FROM THE TOP SHELF. AT THIS POINT, A COMPLETE CRISS-CROSS TRANSFER PATTERN HAD BEEN ACCOMPLISHED. THE SUBJECT THEN WENT AHEAD TO REPEAT THE CYCLE TWO MORE TIMES. AS USUAL, THERE WAS BRIEFING AND PRACTICE BEFORE RECORDING. THE TASK GEOMETRY IS SHOWN IN FIGURE 9.

TASK D - "EQUIPMENT TRANSFER" TASK (TWO MAN)

THIS TASK WAS A VERSION OF TASK C MODIFIED FOR USE BY TWO MEN. IT WAS INCLUDED SO AS TO STUDY THE FEASIBILITY OF COLLECTING ANTHROPOMETRIC SPACE ENVELOPES ON TEAMS OR GROUPS, AS WELL AS TO ACTUALLY MEASURE THE DIMENSIONS WHICH WOULD BE OCCUPIED BY TWO MEN DOING THE TASK. THE TASK GEOMETRY AND RECORDING OF THE DATA WERE IDENTICAL WITH TASK C. HOWEVER, FOUR BOXES WERE USED AND THE PATTERN OF MOVING THEM WAS DIFFERENT. AT THE START, THE SHELVES WERE PRE-LOADED WITH ONE BOX APIECE. AT THE SIGNAL, EACH SUBJECT OCCUPIED A POSITION IN FRONT OF ONE OF THE RACKS. HE THEN REMOVED A BOX FROM THE TOP SHELF AND TRANSPORTED IT ACROSS TO THE TOP SHELF OF THE OTHER MAN'S RACK, PASSING THE OTHER MAN EN ROUTE. THEY THEN SQUATTED DOWN, GOT THE BOXES FROM THE BOTTOM SHELVES AND WALKED TO THE ADJACENT RACK TO PUT THE BOX INTO THE LOWER SHELF. THEY THEN STOOD UP, GOT THE TOP BOXES, AND REPEATED THE CYCLE. A MEASUREMENT SERIES WAS MADE UP OF 3 SUCH CYCLES WITHOUT PAUSE. OBVIOUSLY, SOMEONE HAS TO GO ON THE OUTSIDE WHEN THE MEN MEET BETWEEN RACKS SO STANDARD PROCEDURE WAS LAID DOWN: THE MAN WALKING TOWARD THE BACKBOARD HUGGED THE RACKS WHILE THE

FIGURE 9

EQUIPMENT TRANSFER TASK GEOMETRY
(OVERHEAD VIEW)



OTHER MAN HEADED TOWARD THE CAMERA ALWAYS PASSED TO THE OUTSIDE. PRE-FILMING PRACTICE WAS GIVEN FOR FAMILIARIZATION. SEE FIGURE 9 FOR THE GEOMETRIC RELATIONSHIP.

F. SUBJECTS

IT WAS SEEN THAT, IN THE PRESENT RESEARCH, COLLECTION OF USEFUL DATA AND AN ADEQUATE TEST OF THIS NEW MEASUREMENT SYSTEM COULD BOTH BE ACCOMPLISHED WITH THE USE OF A MINIMUM NUMBER OF SUBJECTS. IN ADDITION, FUNDS FOR THE PROGRAM WERE SEVERELY LIMITED SO THAT A LARGER MEASUREMENT PROGRAM WAS IMPOSSIBLE. THEREFORE, TWO SUBJECTS WITH APPROXIMATELY 90 - 95 PERCENTILE HEIGHT AND WEIGHT MEASUREMENTS AND TWO WITH APPROXIMATELY 5 - 10 PERCENTILE MEASUREMENTS WERE SELECTED TO BE FILMED WHILE PERFORMING THE TASKS.⁷ ALL FOUR SUBJECTS FELL WITHIN THE NAVAL PERSONNEL AGE RANGES, THE 90 - 95 PERCENTILE PERSONNEL BEING NAVAL ENLISTED PERSONNEL AND THE 5 - 10 PERCENTILE BEING HIGH SCHOOL SENIORS.

90 - 95 PERCENTILE	<u>SUBJECTS</u>	<u>HEIGHT</u>	<u>WEIGHT</u>
	X	73.75"	197 LBS.
	Y	74.00"	200 LBS.
5 - 10 PERCENTILE	<u>SUBJECTS</u>	<u>HEIGHT</u>	<u>WEIGHT</u>
	X	63.00"	117 LBS.
	Y	62.00"	110 LBS.

THE 5 - 10 PERCENTILE PERSONNEL DATA HAS NOT BEEN COMPLETELY PROCESSED AND IS NOT ALL PRESENTED IN THIS REPORT. IT WAS THOUGHT THAT MORE USEFUL AND UNIVERSALLY APPLICABLE DATA COULD BE GOTTEN FROM AN IMMEDIATE AND MORE INCLUSIVE STUDY OF 90 - 95 PERCENTILE RESULTS.

7. THESE MEASURES ARE ROUGHLY IN ACCORD WITH THE POOLED DATA DISPLAYED IN THE ANATOMETER PUBLISHED BY ANATOMETRIC ASSOCIATES, POST OFFICE BOX 204, ROCHESTER 10, NEW YORK.

G. FATIGUE

THERE IS A CONSIDERABLE ADVANTAGE TO BE OBTAINED IN PROCURING A METHOD WHICH WOULD PERMIT THE DIRECT RECORDING OF THE INFLUENCE OF FATIGUE UPON THE ACTIONS OF THE HUMAN OPERATOR. IT HAS BEEN SUGGESTED THAT THE METHOD DESCRIBED HEREIN WOULD BE SUITABLE FOR SUCH A PURPOSE. THEREFORE, DATA HAS BEEN OBTAINED ON TRIALS IN WHICH THE SUBJECTS WERE MADE FATIGUED. FOR PURPOSES OF THE TEST, FATIGUE WAS DEFINED AS HAVING OCCURRED AFTER THE SUBJECTS HAD CARRIED OUT TASKS C OR D FOR A PRESCRIBED PERIOD OF TIME. PRELIMINARY ESTIMATES BASED UPON THE ABILITIES OF THE TWO EXPERIMENTERS (BOTH OF WHOM ARE AROUND THE 85 TO 90TH PERCENTILE AND IN FAIR PHYSICAL TRIM) INDICATED THAT GENUINE FATIGUE WAS EVIDENT AFTER AROUND TWENTY MINUTES OF THIS WORK. IT WAS DECIDED, THEREFORE, TO CARRY THE TASKS TO TWENTY-FIVE MINUTES AND THEN RECORD THE "FATIGUED CONDITION" DATA. THE 95TH PERCENTILE MEN WERE ABLE TO LAST OUT THIS DURATION BY MEANS OF CONSIDERABLE EFFORT. THE 5TH PERCENTILE MEN COULD NOT. AT THE END OF ALMOST TWENTY MINUTES, THEY WERE SO WOBBLY AS TO SUGGEST THE POSSIBILITY OF IMMINENT PHYSICAL COLLAPSE. THEREFORE, THEIR RECORDS WERE MADE AT TWENTY MINUTES. NATURALLY, COLLECTION OF DATA ON FATIGUED CONDITION WAS SAVED UNTIL THE END OF EACH OF THE EXPERIMENTAL SESSIONS SO THAT THE OTHER TASKS WERE RUN UNDER "FRESH" CONDITIONS.

H. DATA RECORDING

MASTER DATA RECORDING SHEETS WERE DEVISED WITH SPACES TO RECORD THE FRAME, THREE COORDINATES FOR EACH BODY REFERENCE POINT, TASK DESCRIPTION, OBSERVER DATA, AND SO FORTH. AN EXAMPLE OF THESE SHEETS IS FOUND IN FIGURE 14.

1. DATA PROCESSING

CONSIDERABLE EFFORT WAS DEVOTED TO DETERMINATION OF THE STATISTICAL TREATMENT WHICH WAS REQUIRED FOR THE DATA. ALL FACTORS BEING CONSIDERED, IT BECAME APPARENT THAT THE DATA WHICH WAS AVAILABLE COULD SUPPORT ONLY A VERY ELEMENTARY TREATMENT. ACCORDINGLY, MEANS AND RANGES WERE DEVELOPED AND ARE TABLED AND GRAPHED IN THE RESULTS SECTION WHICH FOLLOWS.

SECTION FOUR

DISCUSSION OF RESULTS

THERE ARE TWO TYPES OF RESULTS IN THIS STUDY. ONE RESULT CONCERNS THE METHOD WHILE THE OTHER CONCERNS THE OUTCOME OF APPLICATION OF THE METHOD.

ONE OBJECTIVE OF THE RESEARCH HAS BEEN TO DEVISE AND CHECK OUT A METHOD FOR RECORDING THE DYNAMIC DIMENSIONS OF THE HUMAN OPERATOR. THIS HAS BEEN DONE, AND SUCCESSFULLY SO. THE SECTIONS WHICH PRECEDE THIS ONE HAVE GIVEN THE RESULTS OF THE EQUIPMENT DEVELOPMENT PROGRAM. IN THOSE SECTIONS WILL BE FOUND A DESCRIPTION OF THE TECHNIQUE. DEVELOPMENT OF THE METHODOLOGY DESCRIBED HEREIN IS THE MAJOR RESULT BEING SOUGHT BY THIS RESEARCH.

A. VALIDATION OF METHOD

QUITE NATURALLY, ONE OF THE FIRST QUESTIONS WHICH MAY BE RAISED IS RELATED TO THE ACCURACY OF THE METHOD. AFTER ALL, OPERATIONS WERE CONDUCTED WITH ONLY SEMI-PROFESSIONAL PHOTOGRAPHIC EQUIPMENT AND WITH A TECHNIQUE WHICH SEEMS TO PERMIT MUCH ROOM FOR PSYCHOPHYSICAL ERROR IN EQUATING REFERENCE SIZES. ACCORDINGLY, A TEST WAS RUN. ONE STAFF MEMBER HUNG SOME PING PONG BALLS AT CAREFULLY MEASURED DISTANCES IN TRIDIMENSIONAL SPACE BEFORE THE CAMERA. THE STRINGS UPON WHICH THE BALLS WERE HUNG COULD NOT BE USED AS CUES. THE BALLS WERE PHOTOGRAPHED AGAINST A FLAT BLACK BACKGROUND. A "TAKE" WAS MADE OF THIS "SCENE". ONLY THE PHOTOGRAPHER KNEW WHAT SCENE HAD BEEN USED AND WHAT DIMENSIONS WERE INVOLVED. THE STAFF MEMBER WHO WAS TO BE RESPONSIBLE FOR DATA REDUCTION WAS THEN GIVEN THE PROCESSED

FILM AND ASKED TO MEASURE THE LOCATIONS OF EACH REFERENCE OBJECT. HE MADE A COMPLETELY "BLIND READING" OF THESE LOCATIONS. THE RESULTS OF HIS INTERPRETATION ARE SHOWN IN FIGURE 10 WHERE HIS OBSERVATIONS ARE COMPARED WITH THE ACTUAL MEASUREMENTS.

PARENTHETICALLY, INFORMAL VALIDITY TESTS HAD BEEN MADE EARLIER WITH PRELIMINARY FILMS. IN THOSE TESTS, THE LOCATION OF THE BALLS WAS JUDGED BY TWO JUDGES AND OVER SEVERAL REPEATED TEST-RETEST SITUATIONS. OF COURSE, AFTER TWO OR THREE TRIALS, THE JUDGES KNEW THE LOCATION OF THE BALLS. STILL, THE TWO JUDGES AGREED RATHER CLOSELY (USUALLY WITHIN $1/2$ INCH) ON LOCATIONS AND WERE QUITE CONSISTENT (USUALLY WITHIN ABOUT $1/2$ INCH) FROM DAY TO DAY. ON THE BASIS OF THESE INFORMAL TESTS, THE RUGGED BLIND-READING TEST WHOSE REVEALING RESULTS ARE SEEN IN FIGURE 10 WAS ESTABLISHED.

FOR PURPOSES OF EVALUATION OF FIGURE 10, IT SHOULD BE POINTED OUT THAT AN ERROR OF $1\frac{1}{2}$ INCH IN THE LONGITUDINAL AXIS AT LOCATION E WOULD BE APPROXIMATELY A 1% ERROR IN MEASUREMENT. A $2\frac{1}{4}$ INCH ERROR WOULD BE REQUIRED ON LOCATION A TO EQUAL AN ERROR OF 1%. (PERHAPS THIS IS MORE MEANINGFUL IF IT IS SAID THAT THIS WOULD BE AN ERROR OF ABOUT TWO INCHES IN JUDGING THE DISTANCE OF AN OBJECT NINETEEN FEET AWAY.) ON THE BASIS OF THIS DATA, PLUS RELATIVELY EXTENSIVE SUBSEQUENT EXPERIENCE WITH REAL SCENE DATA, IT IS BELIEVED THAT THE OVERALL ACCURACY OF THIS DATA SYSTEM IS USUALLY CONSIDERABLY BETTER THAN 1%. THERE IS NO KNOWN CASE OF AN ERROR OF MEASUREMENT LARGER THAN 1%. IT IS BELIEVED THAT THIS LEVEL OF ACCURACY IS DEFINITELY ACCEPTABLE FOR MANY PURPOSES. THIS RESEARCH STAFF IS CERTAIN THAT THE ALREADY SMALL ERRORS IN THIS PRESENT MATERIAL COULD

FIGURE 10

VALIDATION OF THE MEASUREMENT METHODOLOGY

LOCATION	LONGITUDINAL AXIS (Z)			HORIZONTAL AXIS (X)			VERTICAL AXIS (Y)		
	ACTUAL	OBSERVED	ERROR	ACTUAL	OBSERVED	ERROR	ACTUAL	OBSERVED	ERROR
A	15 3/4	16 3/4	-1	R 33 1/4	32	-1 1/4	49	48 1/4	- 3/4
B	42 3/8	43 1/4	- 7/8	L 24 5/8	23 1/8	-1 1/2	15 11/16	16 3/4	+1 1/16
C	51 3/4	50 1/2	+1 1/4	L 19 1/2	20 1/8	+ 5/8	77 3/4	78 3/4	+1
D	56 13/16	56 1/2	+ 5/16	R 16 1/4	15 7/8	- 3/8	34 7/16	34 1/4	- 3/16
E	90 3/4	92 1/4	-1 1/2	R 29 3/8	28 3/8	-1	15 5/8	15 1/2	- 1/8

NOTE 1 LONGITUDINAL AXIS (Z) FIGURES SHOW THE HORIZONTAL DISTANCE FROM AN ARBITRARY REFERENCE POINT LOCATED 20 FEET FROM THE CAMERA MEASURED PARALLEL TO THE OPTICAL AXIS OF THE CAMERA-PROJECTOR SYSTEM.

NOTE 2 HORIZONTAL AXIS (X) FIGURES SHOW THE HORIZONTAL DISTANCE ALONG A PERPENDICULAR TO THE LEFT OR RIGHT OF THE OPTICAL AXIS OF THE CAMERA-PROJECTOR SYSTEM.

NOTE 3 VERTICAL AXIS (Y) FIGURES SHOW THE VERTICAL DISTANCE MEASURED ALONG A PERPENDICULAR FROM THE FLOOR.

NOTE 4 ALL MEASUREMENTS IN INCHES.

BE REDUCED FURTHER WITH APPARATUS AND MEASUREMENT MODIFICATIONS AND BY WORKING AT CLOSER RANGES.

B. EVERY FRAME DATA

AS A DEMONSTRATION OF HOW DATA CAN BE OBTAINED WITH THE METHOD, ONE TASK HAS BEEN COMPLETELY ANALYZED, FRAME BY FRAME. THE RESULTS APPEAR IN FIGURES 11, 12, AND 13. IN THOSE FIGURES HAS BEEN DRAWN A GRAPHIC REPRESENTATION OF THE SAME DATA AS IS SHOWN IN TABULAR FORM IN FIGURE 14. THE TASK USED HERE IS THE "WALK" TASK. THE SUBJECT IS A 95 PERCENTILE MAN. THE DATA RECORD IS NOT STARTED OFF UNTIL THE MAN HAS HIT FULL STRIDE AND IS CUT OFF BEFORE HE BROKE STRIDE AND TURNED OFF THE PATH. THE DIFFERENT FIGURES ARE PLOTS OF IDENTICALLY THE SAME DATA EXAMINED EACH TIME FROM A DIFFERENT ELEVATION. FIGURE 11 RECONSTRUCTS THE VIEW WHICH WOULD BE SEEN DOLLYING ALONG BESIDE THE SUBJECT. FIGURE 12 RECONSTRUCTS THE VIEW OF THE IDENTICAL ACTION AS IT WOULD BE SEEN FROM ABOVE. FIGURE 13 SHOWS WHAT WOULD BE SEEN FROM AHEAD OF THE SUBJECT.

ONE FURTHER ITEM TO NOTE: THIS SUBJECT HAD A SHUFFLING GAIT WHICH CAUSED HIM TO RAISE HIS FEET ONLY A SMALL DISTANCE OFF THE FLOOR, USUALLY $1/2$ INCH OR LESS. IT IS FUTILE TO TRY TO RECORD THIS SINCE IT PROBABLY LIES WITHIN THE ERROR OF MEASUREMENT OF THE METHOD AND IS AN INCONSEQUENTIAL AMOUNT ANYHOW. MEASURES FOR THIS WOULD PROBABLY BE OF INTEREST TO ANYONE STUDYING GAITS, WHEREUPON ONE WOULD FIND IT APPROPRIATE TO GO TO THE TROUBLE OF MEASURING.

THE REALLY SIGNIFICANT POINTS OF THE DATA ARE THESE: ALL THREE VIEW OF THE SUBJECT ARE RECONSTRUCTED FROM ONE CAMERA, ONE EXPOSURE, TIME-BOUND RECORD. FURTHERMORE, AND THIS SETS THE TECHNIQUE CLEARLY APART FROM ITS PREDECESSORS, ACCURATE DIMENSIONS AND ACCURATE DISTANCES (AND THEREFORE VELOCITIES) CAN BE DIRECTLY OBTAINED. WHILE LIGHT STREAKS WILL SHOW PATTERNS OF MOTION AND STROBOSCOPIC TECHNIQUES WILL SHOW VELOCITIES, THE PRESENT TECHNIQUE WILL ACCOMPLISH BOTH OF THOSE OBJECTIVES AND, IN ADDITION, GIVE ACCURATE POSITIONAL INFORMATION IN SPACE. THIS CAPABILITY IS THOUGHT TO BE A RELATIVELY SIZEABLE INNOVATION.

FROM THE ABOVE EXAMPLES, IT IS APPARENT THAT MOST, IF NOT ALL, OF THE PURPOSES FOR WHICH PHOTOGRAPHIC RECORDING OF MOTION HAS BEEN USED IN THE PAST CAN BE CARRIED OUT WITH THE PRESENT TECHNIQUE. FOR EXAMPLE, STUDIES OF PROSTHETIC DEVICES, TIME AND MOTION, SPACE LAYOUTS, CENTERS OF ROTATION, AND MANY OTHERS CAN ALL BE ACCOMPLISHED.

C. ENVELOPE DIMENSION DATA

FOR THE PURPOSE OF DEFINING THE LIMITS OF THE ENVELOPE OF SPACE AS DESCRIBED BY THE MOVING OPERATOR, IT IS NOT NECESSARY TO GO THROUGH ALL THE WORK SHOWN IN THE PRECEDING SECTION. INSTEAD, IT WOULD BE QUITE SUFFICIENT TO KNOW SOME MEASURE OF THE MAXIMUM AMPLITUDES REACHED BY THE BODY PART. ACTUALLY, SUCH A NUMBER COULD BE SIMPLY THE MAXIMUM RANGE REACHED BY EACH PART. IN THE CASE OF THE DATA OF PRECEDING SECTION, THIS WOULD YIELD A FIGURE SUCH AS FIGURE 15. THAT FIGURE IS ONLY BASED ON ONE PASS OF THE SUBJECT. USING THE RANGE IS RELYING UPON A BAD ENOUGH STATISTIC, BUT USING THE RANGE OF ONLY ONE PASS OF ONE PERSON IS TOTALLY INDEFENSIBLE.

IN THE DATA COLLECTION RUNS EACH TASK WAS CARRIED THROUGH THREE CYCLES BY EACH SUBJECT. THIS MEANS THAT IN TASK C, FOR EXAMPLE, EACH SUBJECT WOULD WALK BACK AND FORTH BETWEEN THE TWO RACKS 12 TIMES. IF ONE OBTAINED AN OUTSIDE LIMIT TO THE AMPLITUDE OF MOTION FOR EACH PASSAGE BETWEEN RACKS, HE WOULD HAVE 12 MEASURES OF OUTSIDE LIMIT OF TRAVEL. THIS IS A LARGE ENOUGH NUMBER OF MEASURES TO BEGIN TO BE MEANINGFUL. IF ONE TOOK THE LARGEST MAXIMUM RANGE VALUE AND THE SMALLEST MAXIMUM RANGE VALUE AND THE MEAN MAXIMUM RANGE VALUE, HE WOULD HAVE A PLOT SUCH AS SHOWN IN FIGURE 16. THE WRITERS WOULD BE MUCH MORE PLEASED IF THE STATISTICS USED WERE MEANS AND STANDARD DEVIATIONS INSTEAD OF MEANS AND RANGES. IT IS NOT BELIEVED THAT THE DATA WILL SUPPORT THE COMPUTATION OF STANDARD DEVIATIONS. USE OF STANDARD DEVIATIONS WOULD PERMIT MUCH MORE RATIONAL ASSERTIONS ABOUT THE PROBABILITY OF COLLISIONS WITH OBJECTS WHICH MIGHT CIRCUMSCRIBE THE ENVELOPE IN REAL LIFE (CABINETS, WALLS, DOOR HANDLES, ETC.).

NOTICE THAT FIGURE 16 SHOWS BOTH THE VERTICAL AND HORIZONTAL LIMITS IN THE SAME CHART. IT WOULD BE POSSIBLE TO PREPARE ANOTHER PLOT SHOWING THE RANGES OF MOTION ALONG THE LONGITUDINAL DIMENSION. ALSO NOTICE THAT, IN THE CASE OF FIGURE 18, THE TASK ENVELOPE IS CONSIDERED TO BE BOUNDED ON ONE SIDE BY THE RACKS. HENCE, THE INBOARD BODY PART LOCATIONS WERE NOT READ OUT. THEY COULD BE OBTAINED FROM THE FILMS. SUPPOSE, FOR EXAMPLE, THAT ONE WAS INTERESTED IN HOW LARGE A "PSYCHOLOGICALLY INDUCED CLEARANCE" WOULD BE CREATED BETWEEN THE SUBJECT AND THE PLAIN WALL. NOW

SUPPOSE THE WALL WAS MADE OF SHARP NAIL POINTS---WOULD THE MAN GIVE MORE CLEARANCE? WHAT IF THERE WERE TWO WALLS? WHAT IF BOTH WALLS WERE DANGEROUS? IN OUR PRESENT WORK, WE HAVE MERELY INSTRUCTED THE MAN TO "MOVE THE BOXES BETWEEN THE RACKS BY CARRYING THEM WITH YOUR HANDS". THE RESEARCH POSSIBILITIES INHERENT IN THIS SITUATION ARE OBVIOUS. FIGURES 16 THROUGH 24 SHOW THE DATA FOR ALL OF THE TASKS. SINCE THE LONGITUDINAL DIMENSIONS ARE ARBITRARY RESULTS DICTATED BY THE LOCATION OF THE PROPS, THEY HAVE BEEN OMITTED.

D. DISCUSSION

IT SEEMS TO BE GENERALLY TRUE THAT, BY THE TIME ONE HAS FINISHED A RESEARCH JOB, HE HAS A NUMBER OF IDEAS ABOUT HOW IT COULD HAVE BEEN DONE BETTER. WITH AN EYE TOWARD PROVIDING THE ADVANTAGES OF OUR OBSERVATIONS AND EXPERIENCES TO OTHER RESEARCH PERSONS WHO MAY WISH TO APPLY THIS TECHNIQUE ON THEIR OWN SPECIAL PROBLEMS, THE FOLLOWING COMMENTS ARE OFFERED:

1. CAMERA EQUIPMENT - ONE WOULD BE WELL ADVISED TO OBTAIN BETTER PHOTOGRAPHIC EQUIPMENT. AS THE READER MAY KNOW, THE BOLEX EQUIPMENT USED HERE IS GENERALLY REGARDED AS TOP QUALITY SEMI-PROFESSIONAL OR VERY SERIOUS AMATEUR LEVEL EQUIPMENT. EVEN SO, IT STILL LEAVES A GOOD BIT TO BE DESIRED IN THE PRESENT USE. IF ONE WERE TO EXTEND THE WORK AND IF FINANCES WOULD PERMIT IT, HE SHOULD SEEK OUT FULLY PROFESSIONAL EQUIPMENT. EXAMPLES WHICH MAY BE CONSIDERED INCLUDE 35 MM MITCHELL OR FAIRCHILD OR EQUAL. THE SPECIFIC CAMERA FEATURES WHICH ARE NEEDED INCLUDE:

- A) HIGHLY ACCURATE FILM TRANSPORT (BOTH IN TIME AND REGISTRATION)
- B) A VARIABLE SHUTTER (THE USUAL FIXED RATIO SHUTTER EXPOSURE WILL NOT STOP MOTION EXCEPT AT EXTREMELY HIGH FILM TRANSPORT SPEEDS.)

THESE SPEEDS ARE UNECONOMICAL SINCE IT IS SELDOM THAT EACH FRAME WOULD BE ANALYZED)

- C) REALLY GOOD, VERY WIDE ANGLE LENSES TO PERMIT SHOTS CLOSER TO THE SUBJECT (ANAMORPHICS, WHILE SATISFACTORY FOR SOME PURPOSES, PRESENT DATA REDUCTION PROBLEMS HERE)
- D) ELECTRIC MOTOR DRIVE
- E) HIGHLY ACCURATE SPEED CONTROL (ELIMINATES NEED FOR CLOCKS)
- F) HIGHLY ACCURATE FRAME COUNT
- G) PROVISION FOR CONCURRENT MAGNETIC STRIPE SOUND RECORDING
- H) PROVISION FOR AT LEAST 400 FOOT REELS FOR RECORDING LENGTHY TASKS OR REPETITIVE CYCLES

2. PROJECTION EQUIPMENT - DESIRABLE CHARACTERISTICS FOR THE PROJECTOR

WOULD INCLUDE:

- A) A HIGH ACCURACY IN VERTICAL, HORIZONTAL AND LONGITUDINAL POSITIONING OF EACH FRAME IN THE GATE. THIS ACCURACY IS DESIRABLE IN ALL MODES---MOVIE AND FORWARD HAND CRANK; BUT ESPECIALLY IN REVERSING OR ROCKING BACK AND FORTH BETWEEN ADJACENT PICTURES. IT IS VERY IMPORTANT THAT THERE BE NO NECESSITY TO REFOCUS WHEN GOING FROM ONE MODE OF OPERATION TO ANOTHER.
- B) A COOLING SYSTEM WHICH ABSOLUTELY AVOIDS ANY TENDENCY FOR FLUTTER OF THE FILM IN THE GATE; ALSO A SYSTEM WHICH DOES NOT ALLOW THE FILM TO SHIFT PLANES OR BUCKLE, NECESSITATING REFOCUSING AFTER CONTINUED EXPOSURE.
- C) EITHER AN AUTOFOCUS SYSTEM OR A REMOTE FOCUS SYSTEM WOULD BE VERY HELPFUL.
- D) A TWO-STAGE COUNTER WOULD BE USEFUL IN FINDING TAKES IN REELS AND RECORDING EVENTS WITHIN TAKES.
- E) USE OF THE SAME LENS FOR BOTH PROJECTOR AND CAMERA HAS OBVIOUS ADVANTAGES IN SCALING.

3. MISCELLANEOUS DETAILS -

- A) USE OF VERY FINE GRAINED FILM AND EXTRA SKILL IN PHOTOGRAPHIC PROCESSING ARE STRONGLY SUGGESTED IF ONE IS FORCED TO STICK WITH 16 MM GEAR. DEMONSTRATION HAS BEEN MADE IN THIS REPORT THAT THE WORK CAN BE DONE WITH 16 MM GEAR, BUT, AS MANY PHOTOGRAPHERS KNOW, MINIATURIZATION BRINGS A CONCURRENT REQUIREMENT FOR EXTRA CARE.
- B) USE OF LARGER REFERENCE OBJECTS IS DESIRABLE WHEREVER POSSIBLE (E.G., ATOP HEAD). A LARGER OBJECT WILL PROVIDE A BETTER IMAGE UPON WHICH TO RANGE THAN DOES THE PING PONG BALL. A CELLULOID SPHERE THE SIZE OF A BASEBALL WOULD BE FINE IF USED WHERE IT DID NOT INTERFERE WITH TASK PERFORMANCE.
- C) PROVISION OF A SMALL COLLIMATED TARGET PROJECTOR WHICH USES A BEAM SPLITTING PROCEDURE TO THROW ITS BEAM DIRECTLY DOWN THE OPTICAL

AXIS WOULD BE HELPFUL. IT WOULD CAUSE THE AXIS TO BE VISIBLE DIRECTLY ON THE BODY OF THE SUBJECT AT ANY TIME HIS BODY INTERCEPTED THE AXIS. THIS WOULD DO AWAY WITH THE PROBLEM OF LOSING SIGHT OF THE AXIS ON THE BACKBOARD WHEN THE MAN GOT INTO THE LINE OF SIGHT AND THE RESULTING NECESSITY TO RECONSTITUTE THE LOCATION OF THE AXIS BEFORE MEASURING THE X AND Y COORDINATES.

ON THE FOLLOWING PAGES WILL BE FOUND REPRESENTATIVE DATA DRAWN FROM THE RESULTS OF THE EXPERIMENTS. FIGURES 11-14 SHOW THE KIND OF DATA WHICH RESULTS FROM PLOTTING THE REFERENCE POINTS ON EVERY FRAME COMPLETELY IN THREE DIMENSIONS. FIGURE 15 SHOWS THE OUTSIDE LIMITS OF THE ENVELOPE AND HOW THEY MIGHT BE DEPICTED. FIGURES 16-24 SHOW THE LOCATIONS OF THE MAXIMUM EXCURSIONS GENERATED AT A VARIETY OF TASKS UNDER A VARIETY OF CIRCUMSTANCES. IT IS IMPORTANT TO RECOGNIZE THAT THE OUTSIDE LIMITS AS DEFINED IN A FIGURE SUCH AS FIGURE 15 ARE BASED ON RANGE STATISTICS. IF ONE IS WILLING TO RELY ON THE RANGE, THEN THESE LIMITS WOULD DEFINE THE MAXIMUM ENCROACHMENT WHICH COULD BE MADE BY THE AMBIENT SURROUNDS WITHOUT INTRUDING ON THE ENVELOPE OF SPACE REQUIRED BY THE HUMAN. UPON STUDY, IT WILL BECOME APPARENT THAT THERE ARE MANY ADDITIONAL POSSIBILITIES FOR TREATING DATA OF THIS SORT; PERHAPS OTHER METHODS OF PRESENTATION WOULD BE MORE APPROPRIATE FOR SPECIFIC PURPOSES. THE FIGURES SHOWN HERE ARE INTENDED SOLELY FOR PURPOSES OF ILLUSTRATION AND ARE NOT MEANT TO BE AN EXHAUSTIVE ACCOUNT OF THE RESEARCH.

FIGURE 11

REPRESENTATIVE COMPLETE DATA ANALYSIS

95TH PERCENTILE SUBJECT - "WALK" TASK - SIDE VIEW- EVERY FRAME ANALYZED

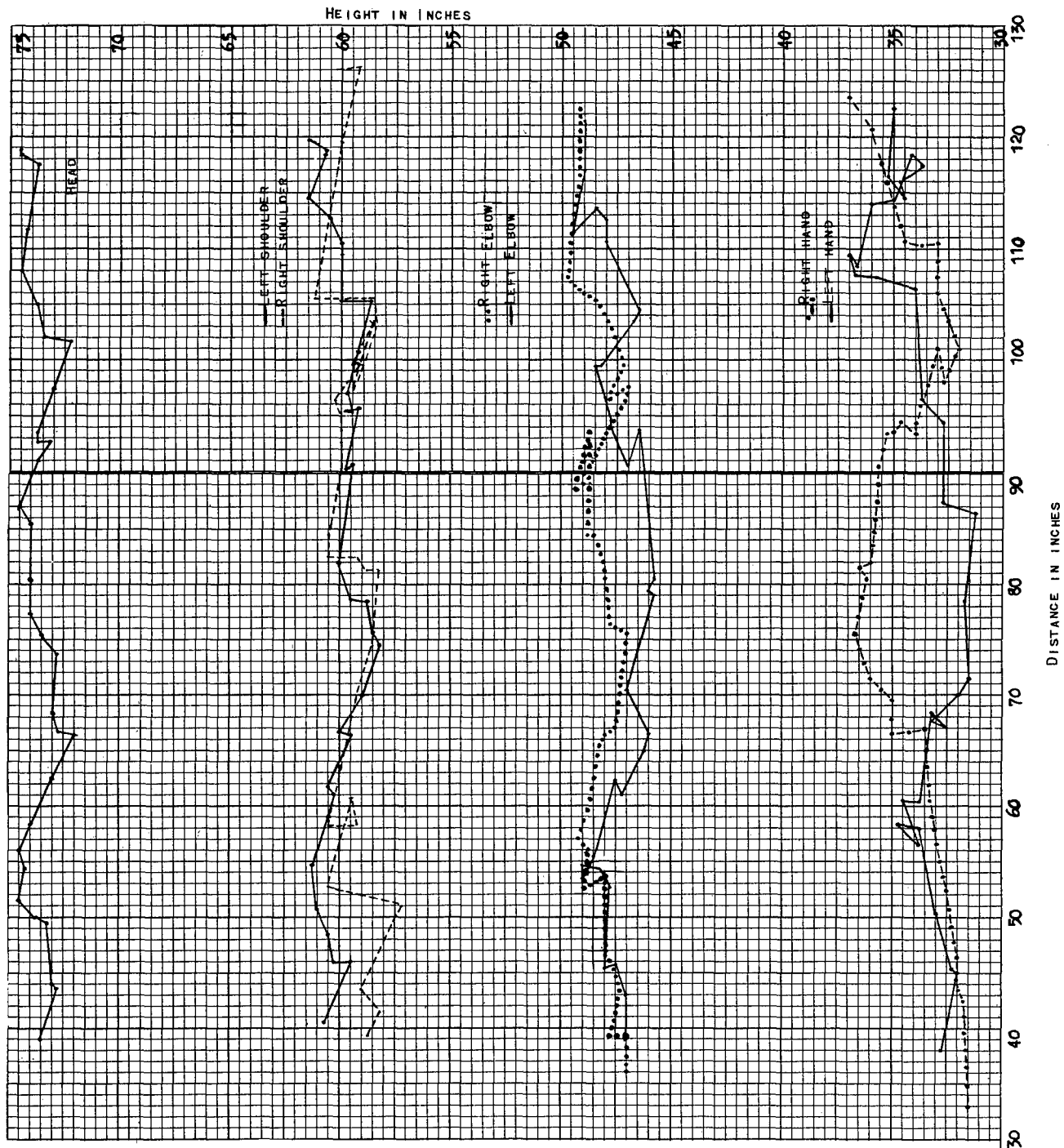


FIGURE 12

REPRESENTATIVE COMPLETE DATA ANALYSIS

95TH PERCENTILE SUBJECT - "WALK" TASK - OVERHEAD VIEW - EVERY FRAME ANALYZED

(NOTE: DATA INCOMPLETE ON RIGHT FOOT)

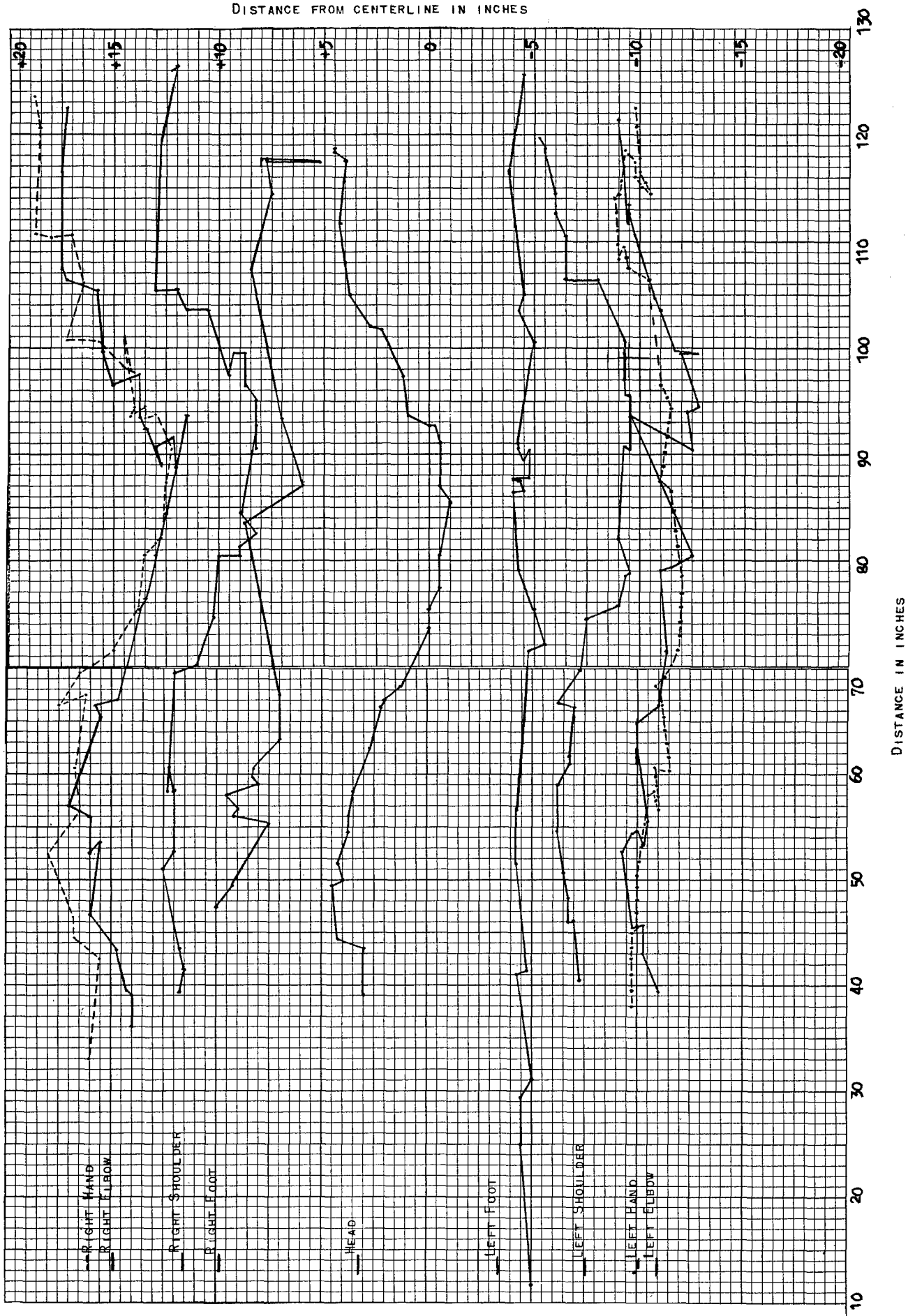


FIGURE 13

REPRESENTATIVE COMPLETE DATA ANALYSIS

95TH PERCENTILE SUBJECT - "WALK" TASK - END VIEW

(NOTE: DATA INCOMPLETE ON RIGHT FOOT)

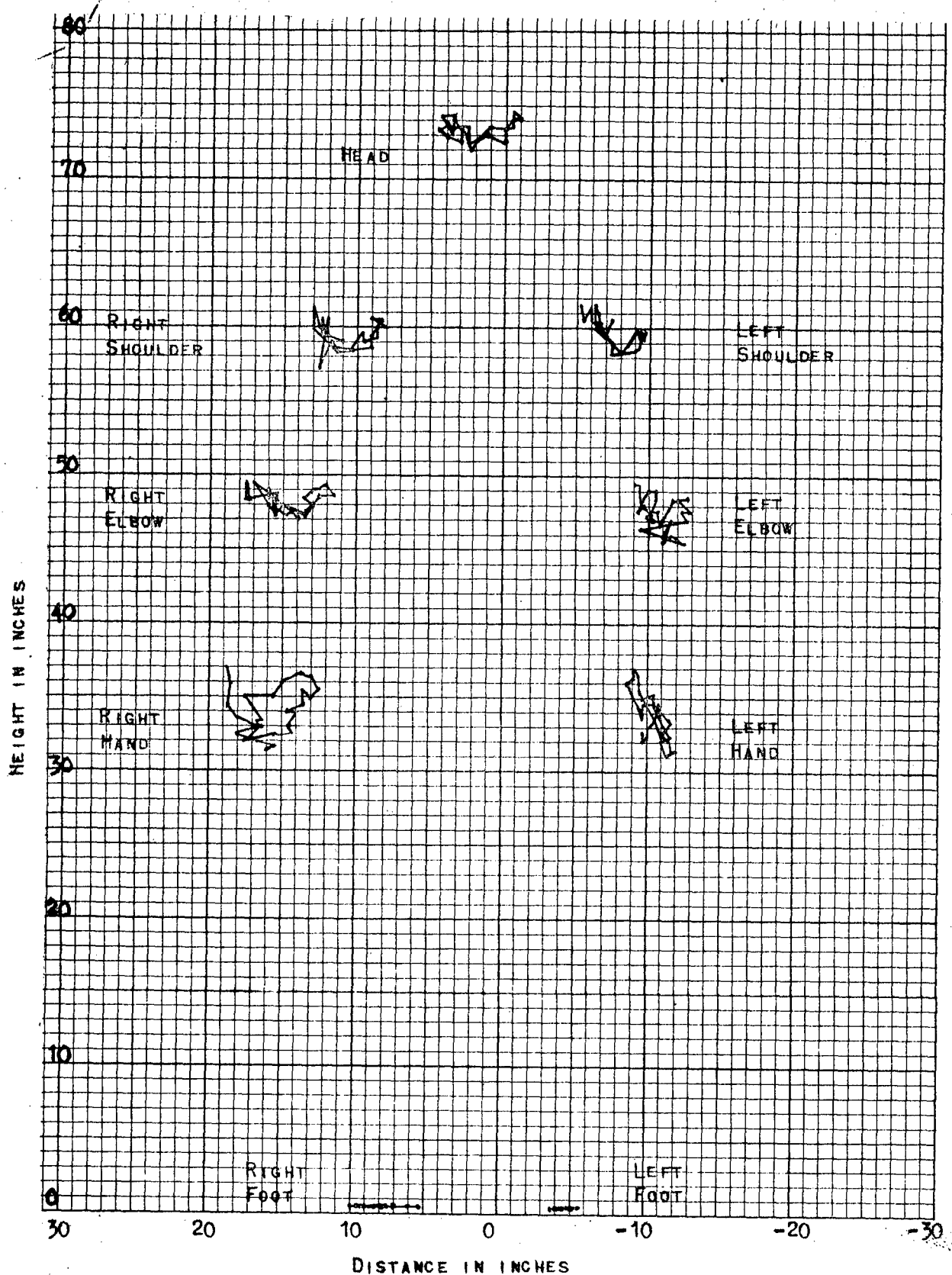


FIGURE 14
EVERY FRAME ANALYSIS OF WALKING TASK

FRAME	HEAD			LEFT SHOULDER			RIGHT SHOULDER			LEFT ELBOW		
	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	HEIGHT
25	39	3	73 1/2	40 1/2	-7 1/4	60 3/4	39 1/4	11 3/4	58 3/4	39 1/4	-11	47
26	43 3/4	3	72 3/4	46	-7	59 1/2	41 1/2	11 1/2	58 1/4	43	-10 1/4	47
27	44	4 1/4	73	46	-6 3/4	60 1/4	43 1/2	11 3/4	59	45 3/4	-10 1/4	47 1/2
28	49 1/2	4 1/2	73 1/4	48 1/4	-6 3/4	60 1/2	51	12 1/2	57 1/4	45 1/2	-9 3/4	48
29	50	4	73 3/4	50 3/4	-6 1/2	61	52 3/4	12	60 1/2	52 3/4	-9 1/4	47 3/4
30	51 1/2	4 1/4	74 1/2	54 3/4	-6 1/4	61 1/4	58 1/4	12	59 3/4	54 1/4	-9 3/4	48 1/4
31	54 1/4	3 3/4	74 1/4	59	-6 1/4	60 1/2	60 3/4	12 1/4	59 1/2	54 3/4	-10	49
32	56	3 3/4	74 1/2	61	-6 3/4	60 1/4	58 1/4	12 1/4	59 1/4	53 1/4	-10 1/4	49
33	58 1/4	3 1/2	74	61 3/4	-6 1/2	60 1/2	58 1/4	12 1/4	60 1/2	55 1/2	-10 1/2	48 1/2
34	62 1/2	2 3/4	73	66 1/4	-7	59 1/2	69 3/4	12	59 1/4	62 1/4	-10	47 1/2
35	66 1/4	2 1/4	72	66 3/4	-6 1/4	60	70	11	59	61	-10	47 1/4
36	67 3/4	2	72 3/4	70	-7 1/4	59	74 1/2	10 1/4	58 1/2	65	-10	46 1/4
37	68 1/4	1 1/4	73	74 1/2	-7 1/4	58 1/4	81 1/4	10	58 1/4	66 1/2	-11	46
38	73 3/4	0	72 3/4	75 3/4	-9	58 1/2	81 1/4	9	58 3/4	71 1/4	-11 1/4	47
39	75 1/4	0	73 1/2	78 1/2	-9 1/4	58 3/4	82 1/4	9	59 1/4	79	-11	45 3/4
40	77 1/4	1/2	74	78 3/4	-9 1/2	59 1/2	82 1/2	8 1/4	60 1/2	79 1/4	-11 1/2	46
41	80 1/2	-1/2	74	82	-9	60	84 1/2	9	60 1/2	80 1/2	-12 1/2	45 3/4
42	85 1/2	-1	74	90 3/4	-9 1/4	59 1/2	92 3/4	8 1/4	60	93 3/4	-9 1/2	46 1/2
43	87	-1/2	74 1/2	90 1/4	-9 1/2	59 3/4	90 1/4	8 3/4	60	90 1/4	-12 1/2	47
44	91	-1/2	73 3/4	95 3/4	-9 1/2	59 1/4	95	8 1/4	60	94	-12 1/4	47 3/4
45	92 3/4	1/4	73 1/4	95 1/2	-9 1/4	59 3/4	96 1/4	8 3/4	60 1/4	94 3/4	-12 3/4	47 3/4
46	92 3/4	1/2	73 3/4	95 1/2	-9 1/4	59 1/2	99 1/2	8 3/4	59 1/4	99 1/2	-12	48 1/4
47	93 3/4	1	73 3/4	97	-9 1/4	59 3/4	99 1/2	9 1/4	59	99 1/2	-12 3/4	48 1/2
48	97 1/4	1 1/4	73	100 3/4	-9 1/4	59 1/4	97 1/2	9 1/2	59 1/2	99 3/4	-11 3/4	48 1/4
49	101 3/4	2 1/4	72 1/4	106 1/4	-8	58 3/4	103 1/2	10 1/2	58 1/2	103 1/2	-11	46 3/4
50	102	2 3/4	73 1/2	106 1/4	-6 1/2	60	103 1/2	11 1/2	58 3/4	104 3/4	-10 3/4	47 1/2
51	105	3 3/4	73 3/4	110 1/2	-6 1/2	60	105 1/2	12	59 1/2	110 3/4	-9 3/4	48
52	108	4	74 1/2	112 3/4	-6	60 1/2	105 1/4	13	60	112 3/4	-9 1/2	48
53	111 3/4	4 1/4	74 1/4	114 1/2	-6	61 1/2	105 1/2	13	61 1/4	113 1/2	-9 1/2	48 1/2
54	117 1/2	4	73 3/4	118 3/4	-5 1/2	60 3/4	119 1/2	12 3/4	60	111 3/4	-9 1/2	49 1/2
55	118 1/4	4 1/2	74 1/2	118 1/4	-5 1/2	60 3/4	126 1/4	12	59 1/4	117	-9 1/4	49
56	118 1/2	4 1/2	74 1/2	119 3/4	-5 1/4	61 1/2	126	12 1/4	60 1/4	121 1/4	-9	49

FIGURE 14 (CONTINUED)

EVERY FRAME ANALYSIS OF WALKING TASK

FRAME	RIGHT ELBOW			LEFT HAND			RIGHT HAND			LEFT FOOT		RIGHT FOOT	
	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	HEIGHT	DEPTH	WIDTH	DEPTH	WIDTH
25	36	14	47	38	- 9 3/4	32 3/4	33	16	31 1/2	11 3/4	-5	47 1/4	10
26	39	14	47	45	- 9 3/4	32 1/4	42	15 1/2	31 3/4	25	-4 1/2	47 1/4	10
27	39	14 1/4	47 3/4	45 1/4	- 9 3/4	32 1/4	44	16 3/4	32	29 1/4	-4 1/2	49 1/2	9 1/4
28	43	14 3/4	47 1/4	50 1/4	-10	33	46	16 3/4	32	31	-5	55 1/4	7 1/2
29	46	16	48	58	-10 1/2	33 3/4	52	18	32 1/2	41	-4 1/4	55 1/4	7 1/2
30	53	15 1/2	48	58 1/4	-10 3/4	34 3/4	56	16 1/2	33	41 1/4	-4 3/4	56	9 1/4
31	52	16	49	56 3/4	-11	33 3/4	60	16 3/4	33 1/4	51 3/4	-4 1/4	56	9 1/4
32	56	16	48 3/4	60 1/2	-10 3/4	34 1/2	67	16 1/4	33 1/2	56 3/4	-4 1/4	56 3/4	9
33	57	17	49 1/4	60 1/4	-11 1/2	33 3/4	66	17 1/2	35	71 1/4	-4 3/4	56 3/4	9
34	65	15 1/4	48 1/4	68 1/4	-10 3/4	33 1/4	69	15 1/2	35	72	-5 1/2	58	9 1/2
35	66	15 3/4	48	67	-11	32 1/2	71	15	36	75 1/4	-5	59	8
36	67	14 3/4	47 1/2	67 3/4	-11 1/2	32 3/4	75	13 3/4	36 3/4	79 1/4	-4 1/4	59 3/4	8 1/4
37	75	13 1/2	47 3/4	70	-11 3/4	31 1/2	80	13 1/2	36 1/4	86 1/4	-4	60 1/2	8 1/4
38	76	13 1/2	48	71 1/2	-11 3/4	31 3/4	81	13	36 1/2	86	-4	63 1/4	7
39	80	12 1/2	48 1/2	78 1/2	-12	31 1/4	82	12 3/4	36	86	-4	67 1/2	7
40	84	12 1/2	48 3/4	86 1/4	-11 1/2	32 3/4	87	12 1/2	35 3/4	86	-4	83 1/2	8 3/4
41	84	12 1/2	48 3/4	87 1/4	-11	32 3/4	90	12 1/4	35 3/4	86	-4	87	6
42	93	11 1/2	48 3/4	94 1/4	-11 1/2	33 3/4	93	13	35	86 1/2	-4 1/2	93 1/4	7
43	88	12 1/4	49 1/4	96 1/2	-11	33 3/4	93 3/4	13 1/2	35 1/4	86	-4	107 1/4	8 1/2
44	91	12 1/4	49	106 1/4	-10 1/4	34	94 1/4	14 3/4	34	87 1/2	-4 1/4	114 1/2	7 1/2
45	90	13	49	107 1/4	-9 1/2	35 3/4	94 1/4	14	34	87 1/2	-4	117 1/4	7 3/4
46	89	12 3/4	49	107 3/4	-9 1/4	36 3/4	94 1/4	14 1/2	34	87 1/2	-4 1/2	117 1/4	7 3/4
47	92	13 1/2	48 1/4	109 1/2	-9 1/4	37	101	14 1/2	33	87 1/2	-4	117 1/4	5 1/4
48	93	13 1/4	48	108 1/4	-9	36 3/4	98	14 1/4	32 3/4	87 3/4	-4 1/4	117 1/4	5 1/4
49	97	13 3/4	47	114	-8 3/4	36	100	15 3/4	32 1/4	89 1/2	-4 1/2	117 1/2	7 1/2
50	96	15	48	114 1/4	-9	35	100 3/4	17 1/4	32	90	-4 1/4	117 1/2	7 3/4
51	99	15 1/2	47 1/4	118 1/4	-9 1/4	34 1/4	106	16 1/2	33	91	-4 1/4	117 1/2	5 1/4
52	105	15 3/4	48 1/2	117 1/4	-9 3/4	33 3/4	110	17	33	100 1/2	-5	117 1/2	7 1/2
53	106	17 1/4	49 1/4	116	-9 3/4	34 3/4	110 1/4	18	33 3/4	103 1/2	-4 1/4	117 1/2	7 3/4
54	107	17 1/2	49 3/4	114 1/4	-10 1/2	34 1/2	110 3/4	18 3/4	34 1/2	105	-4 1/2	117 1/2	8
55	116	17 1/2	49 1/4	116 3/4	-10	35 1/4	120 3/4	18 1/2	36	116 1/4	-3 3/4	117 1/2	8
56	122	17 1/4	49 1/4	122 1/2	-9 3/4	35	123 1/2	18 3/4	37	125 3/4	-4 1/2	117	8

+ DATA INCOMPLETE IN THESE FRAMES.

FIGURE 15

MAXIMUM ENVELOPE CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

"WALK" TASK - END VIEW

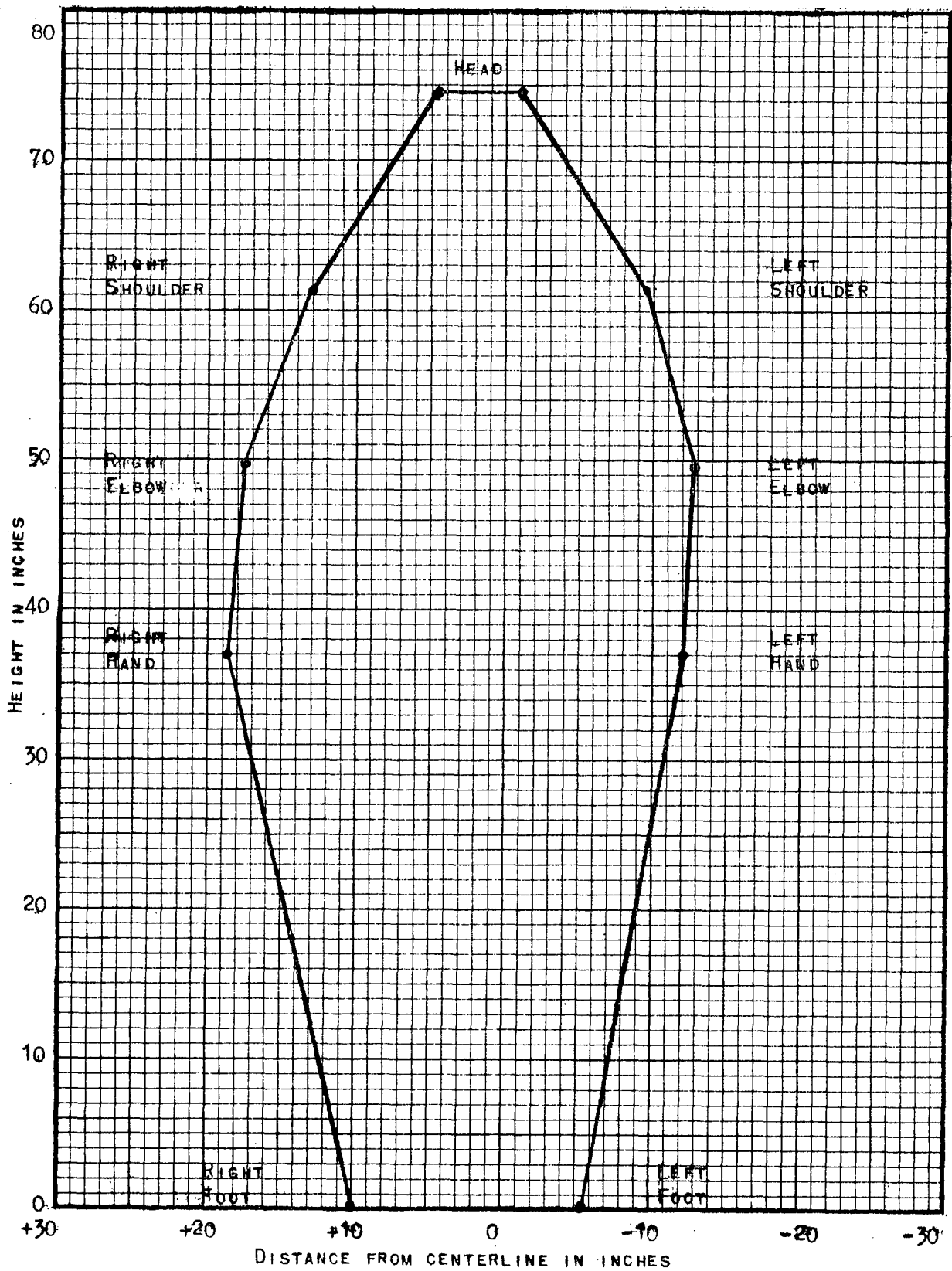


FIGURE 16

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

SUBJECT X - "WALK" TASK - END VIEW

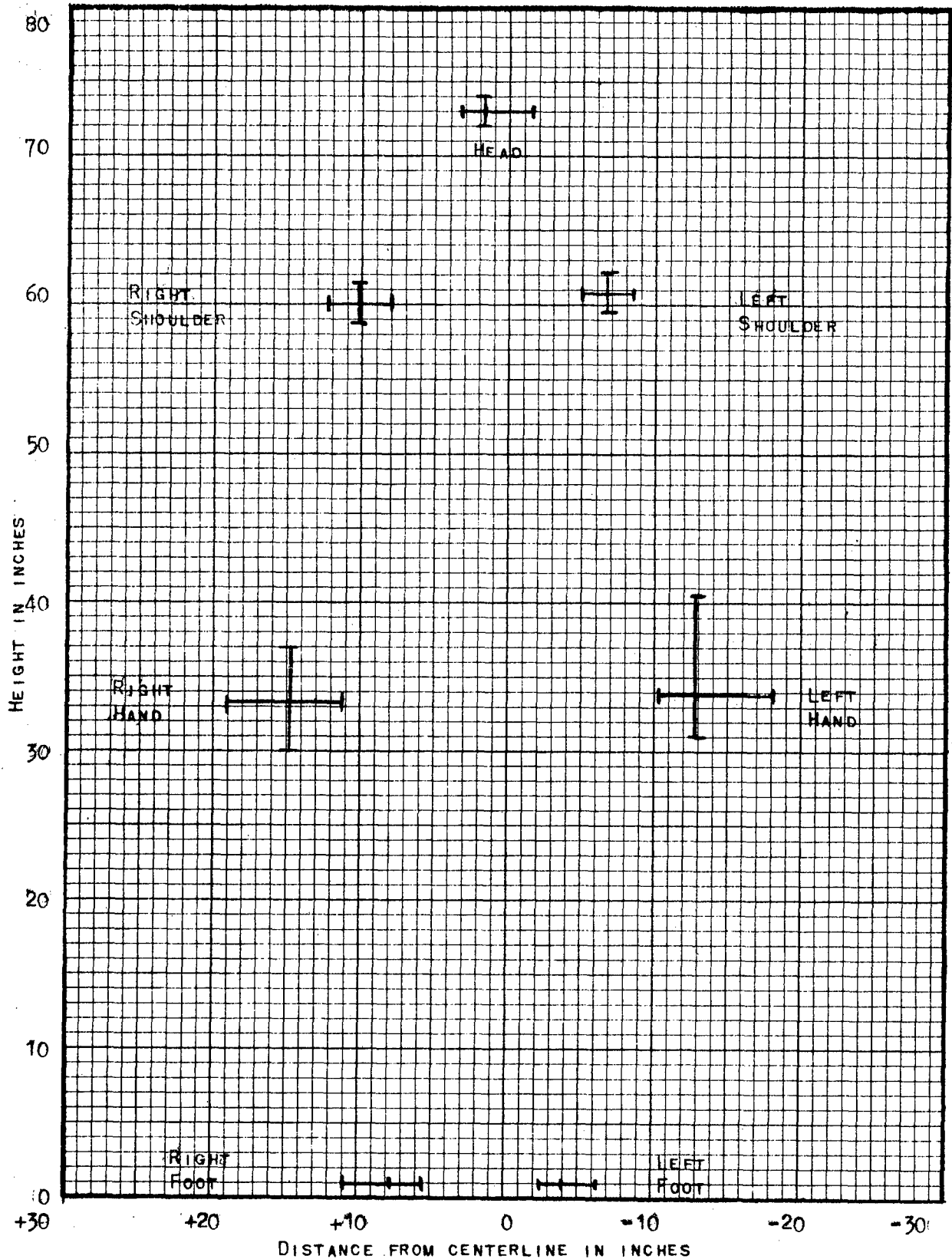


FIGURE 17

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

SUBJECT Y - "WALK" TASK - END VIEW

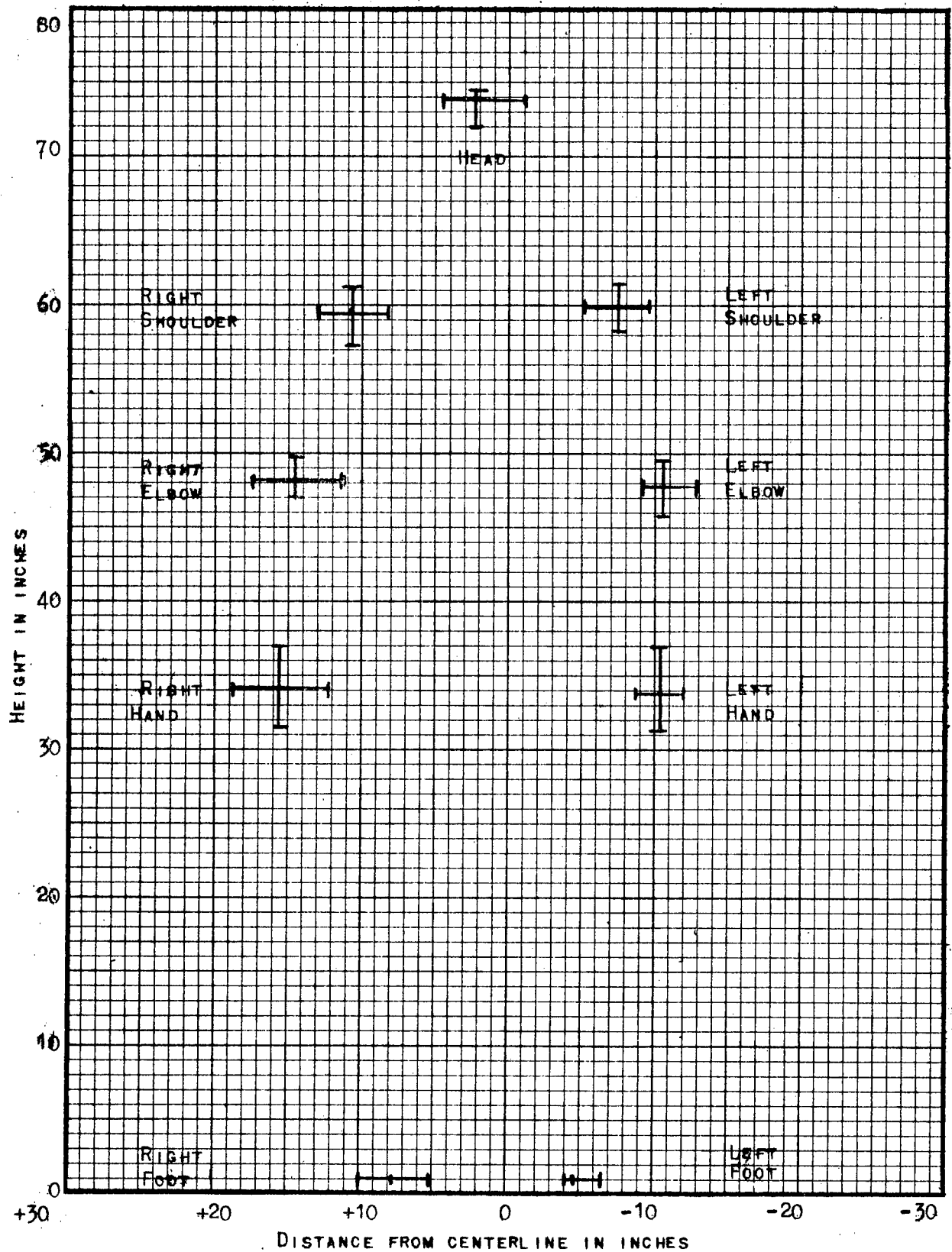


FIGURE 18

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECTS

SUBJECTS X AND Y - "CHANGE PLACES" TASK - END VIEW

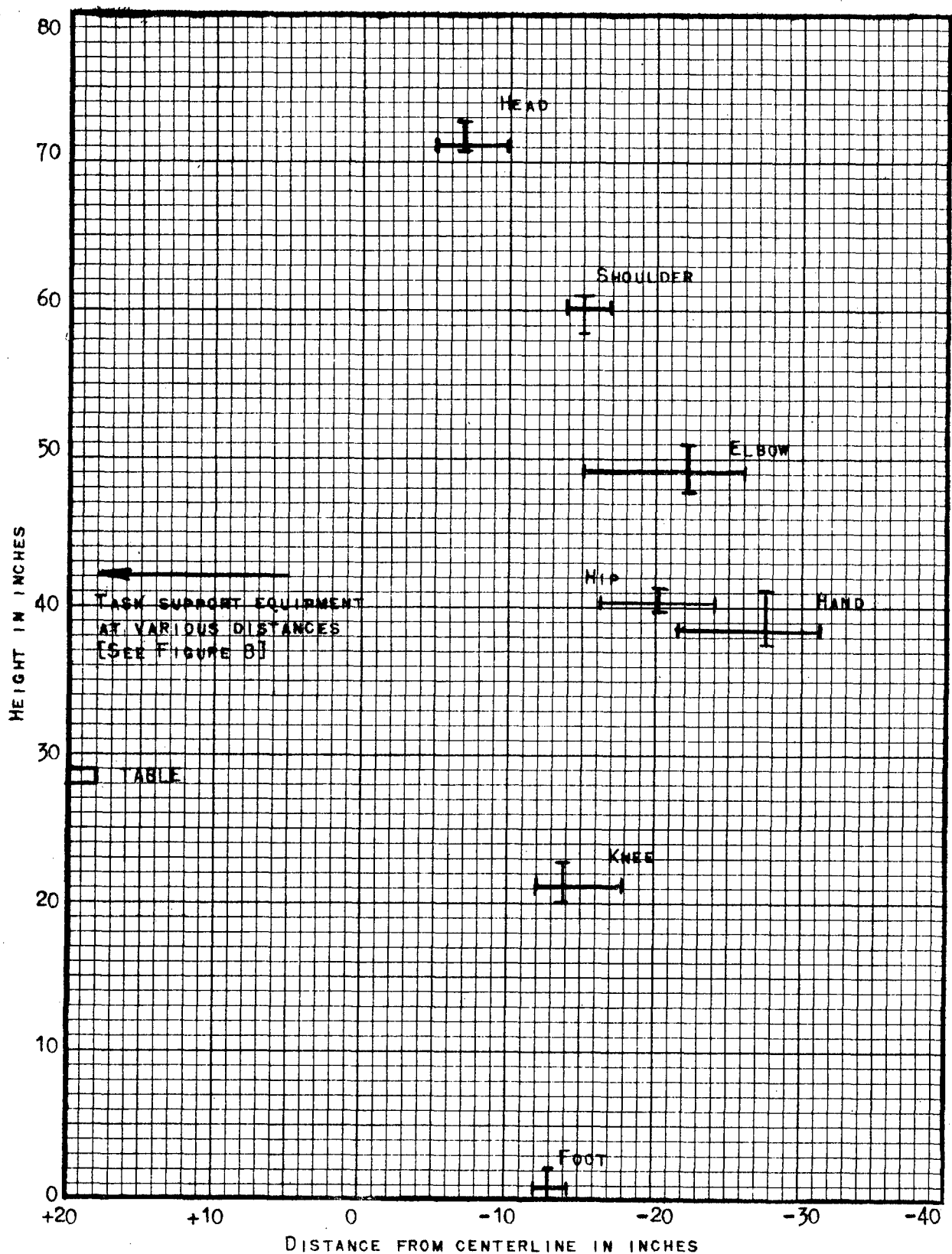


FIGURE 19

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

SUBJECT X - "EQUIPMENT TRANSFER" TASK(ONE MAN) - END VIEW

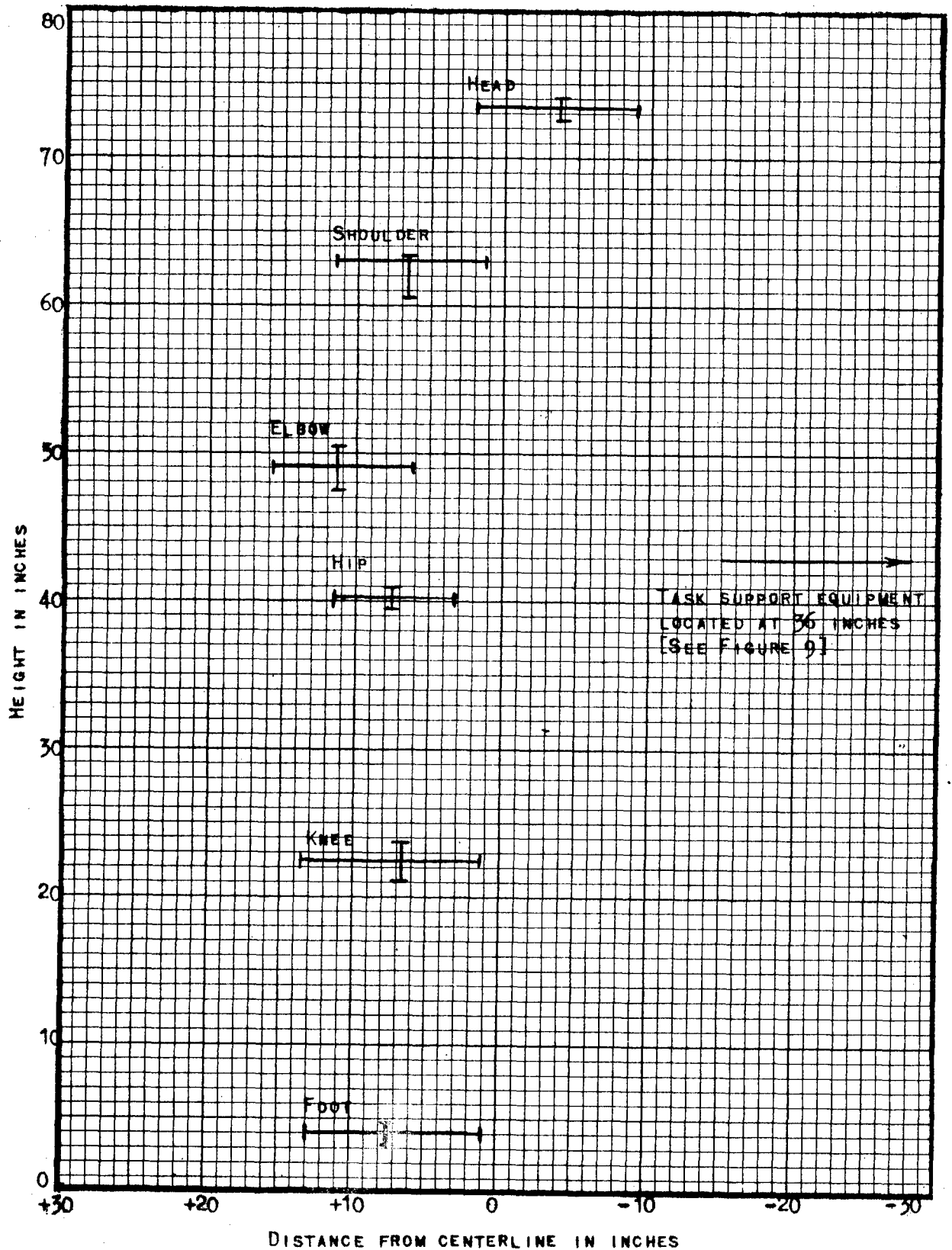


FIGURE 20

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

SUBJECT Y - "EQUIPMENT TRANSFER" TASK (ONE MAN) - END VIEW

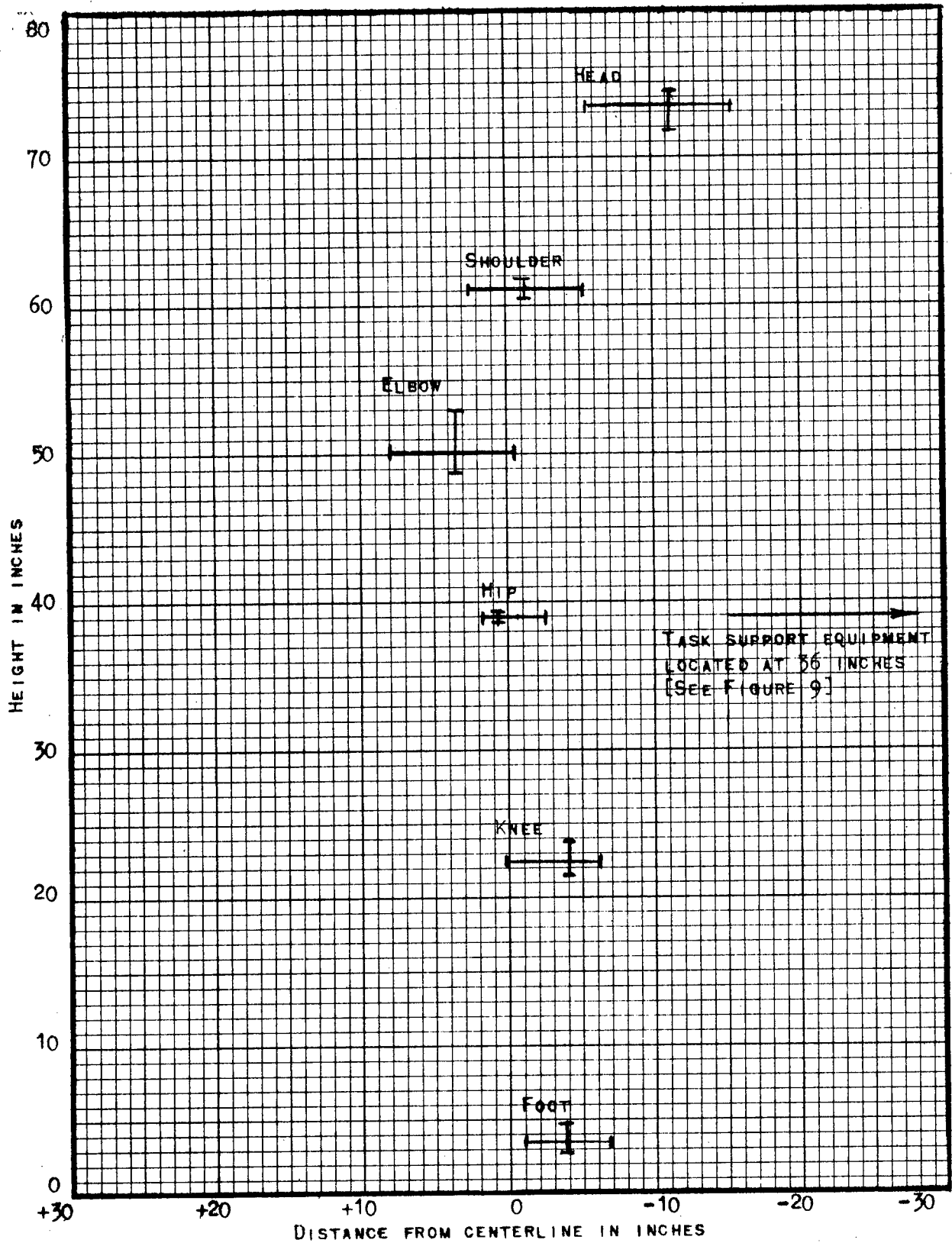


FIGURE 21

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECTS

SUBJECTS X AND Y - "EQUIPMENT TRANSFER" TASK (TWO MAN) - END VIEW

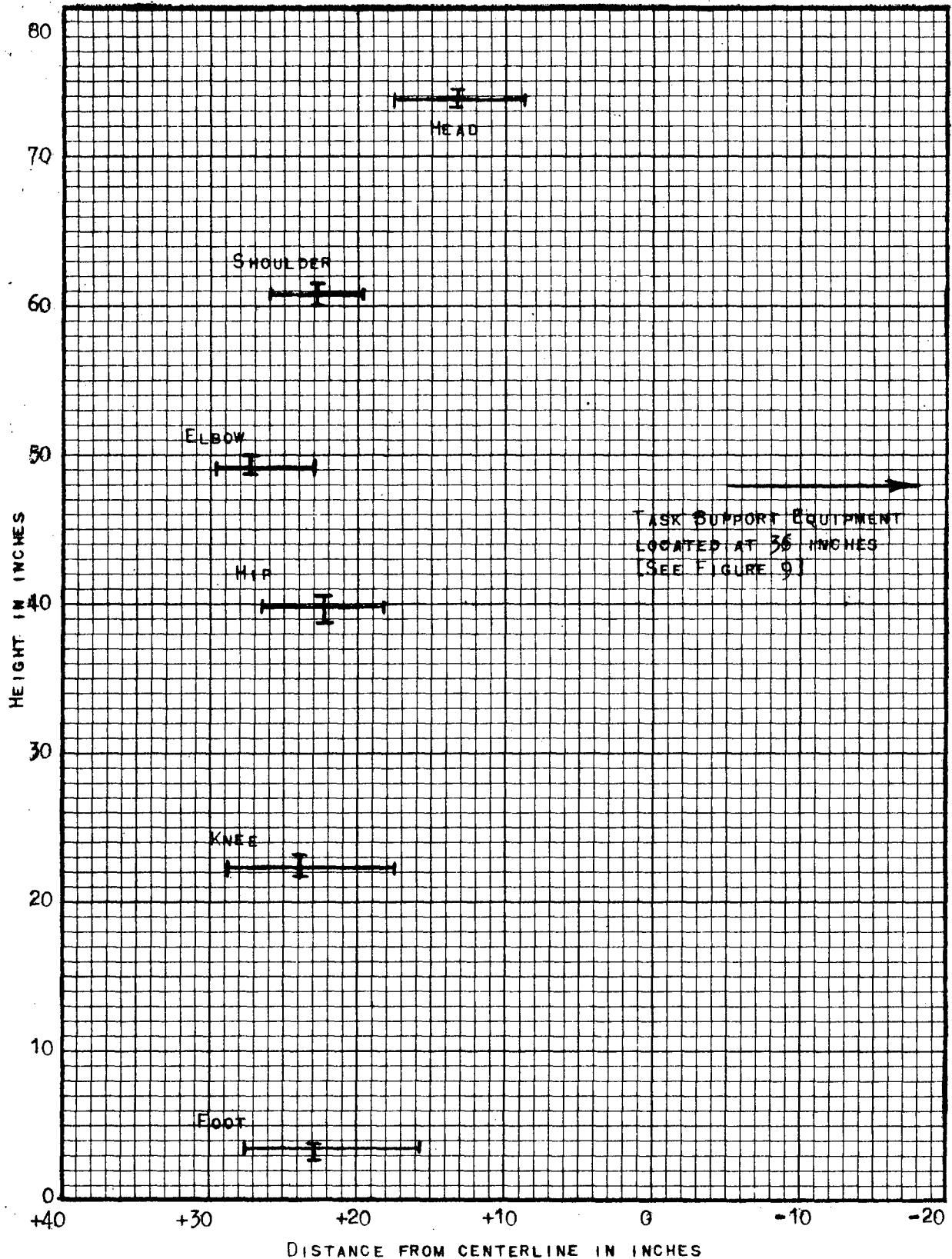


FIGURE 22

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT

SUBJECT X - "EQUIPMENT TRANSFER" TASK (FATIGUED CONDITION) - END VIEW

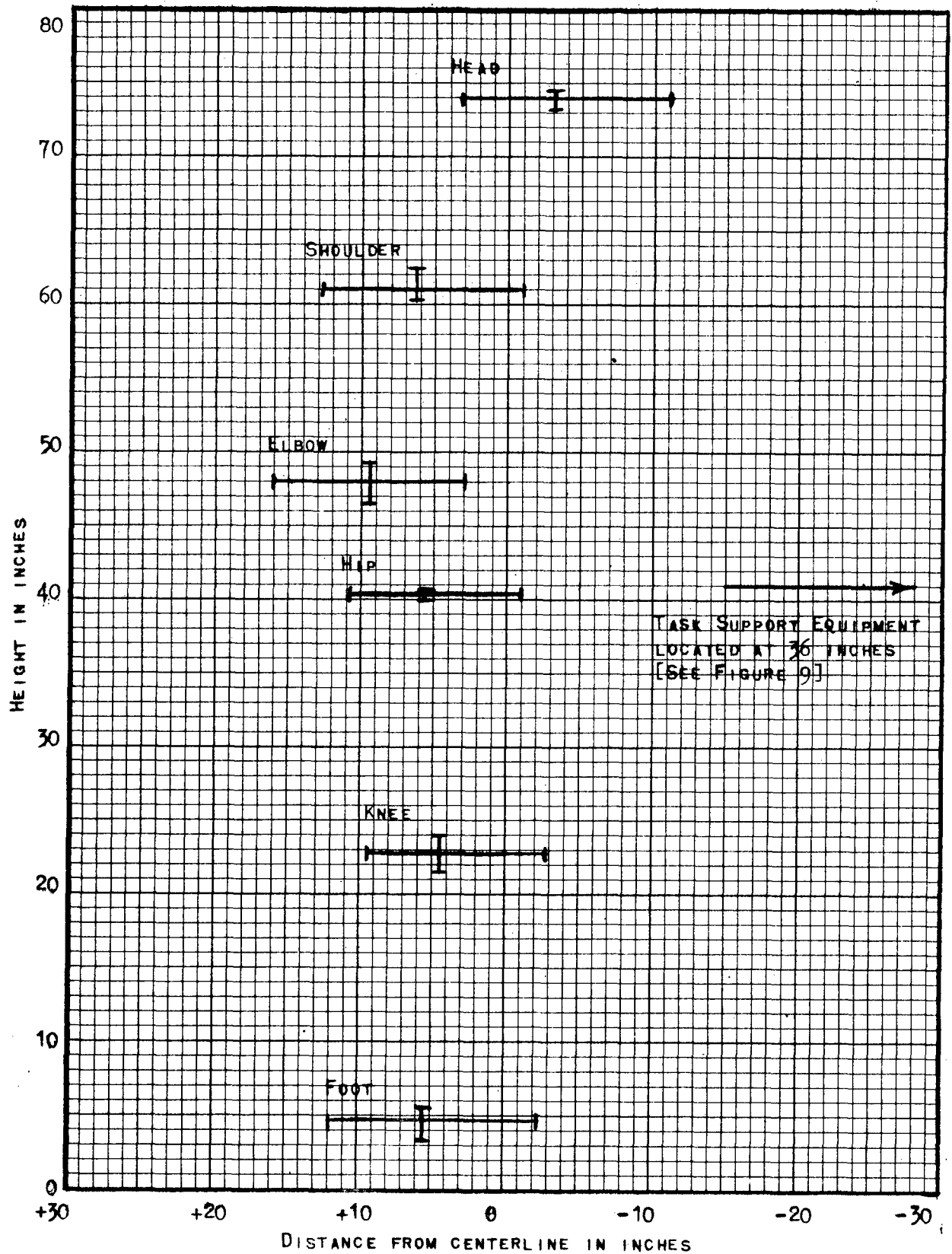


FIGURE 23

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECT
 SUBJECT Y - "EQUIPMENT TRANSFER" TASK (FATIGUED CONDITION) - END VIEW

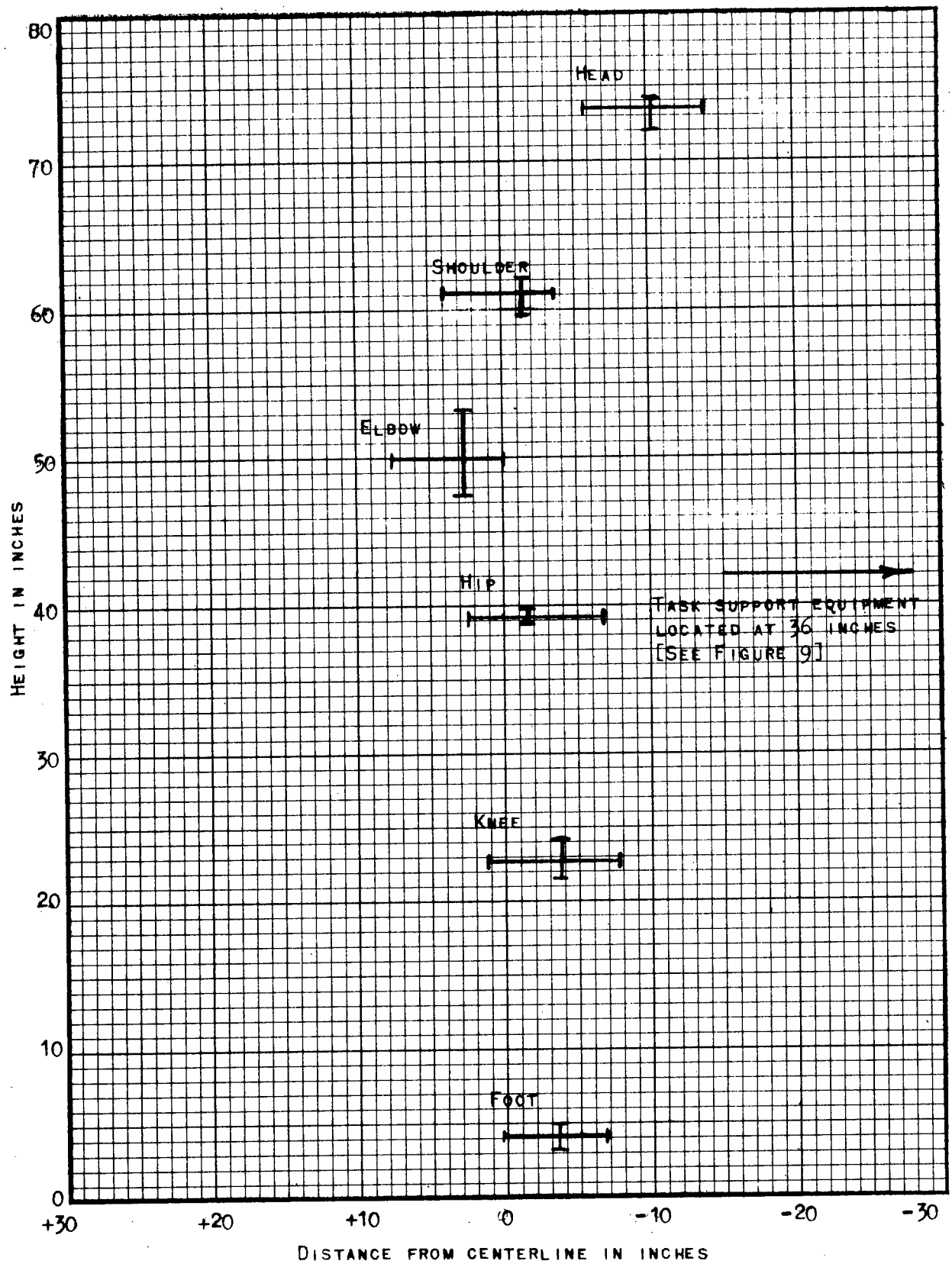
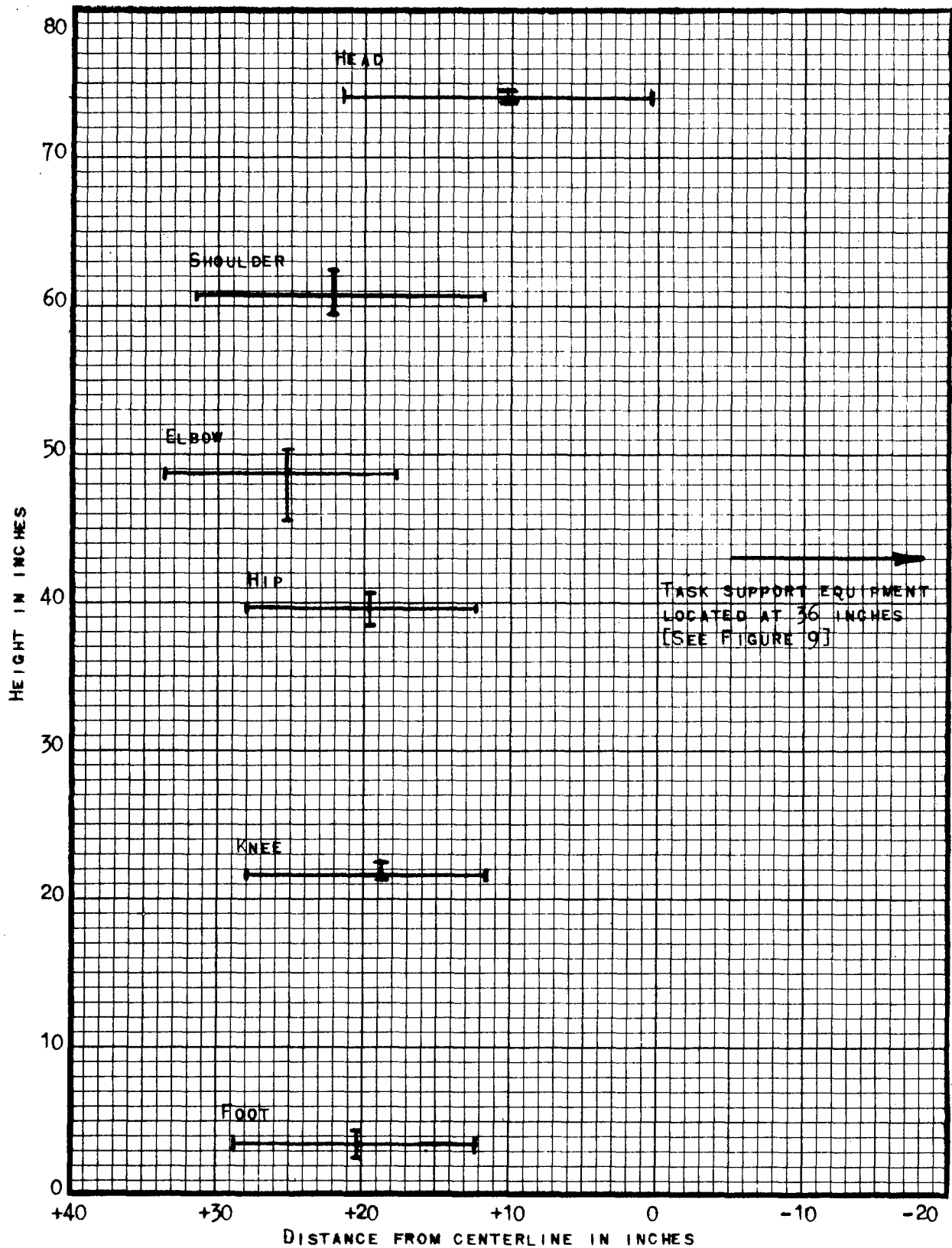


FIGURE 24

MAXIMUM AND MINIMUM DIMENSIONS CIRCUMSCRIBED BY 95TH PERCENTILE SUBJECTS

SUBJECTS X AND Y - "EQUIPMENT TRANSFER" TASK (FATIGUED CONDITION) - END VIEW



SECTION FIVE

SUMMARY

THIS RESEARCH HAS GIVEN EXTENSIVE CONSIDERATION TO THE PROBLEM OF ACQUIRING ACCURATE INFORMATION REGARDING THE CHARACTERISTICS OF THE ENVELOPE OF SPACE OCCUPIED BY THE DYNAMIC HUMAN ENGAGED IN PURPOSEIVE WORK. AFTER CONSIDERABLE FEASIBILITY INVESTIGATION, A METHOD WAS DEVISED WHICH IS SUITABLE FOR THE ACQUISITION OF SUCH DATA. THE METHOD INVOLVES THE USE OF ONE CAMERA MOTION PICTURE PHOTOGRAPHY. THE DATA OBTAINED WILL PROVIDE THE TRIDIMENSIONAL COORDINATES IN TIME AND SPACE OF ANY PORTION OF THE BODY OR OF THE WORKSPACE.

AS A TEST OF THE FEASIBILITY OF THE TECHNIQUE, SEVERAL WORKING TASKS WERE STUDIED. IT WAS DEMONSTRATED THAT THE METHOD IS SUCCESSFUL IN DISCLOSING THE DIMENSIONS, MOTIONS, AND OTHER CHARACTERISTICS OF THE ACTIVE HUMAN AT WORK. BOTH THE METHOD AND THE RESULTS OF THE PRELIMINARY TESTS HAVE BEEN DESCRIBED IN FULL.

SECTION SIX

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