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THE ROLE OF WEIGHING IN THE DEVELOPMENT AND FIRING OF MISSILES AND SPACESHIPS

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LORD KELVIN SAID IN 1883 THAT WHEN YOU CAN MEASURE WHAT YOU ARE SPEAKING ABOUT AND EXPRESS IT IN NUMBERS YOU KNOW SOMETHING ABOUT IT. THIS STATEMENT IS TRUE FOR MOST SCIENTIFIC AND TECHNICAL ACTIVITIES AND IT IS VERY PERTINENT TO THE DEVELOPMENT, FABRICATION AND FIRING OF MISSILES AND SPACESHIPS. MUCH OF OUR SUCCESS AND THE RATE OF PROGRESS DEPENDS HEAVILY UPON THE ACCURACY AND RELIABILITY OF MEASUREMENTS AND GREAT EFFORTS HAVE BEEN MADE DURING THE PAST 30 YEARS OF ROCKET DEVELOPMENT TO OBTAIN DEPENDABLE MEASURING RESULTS. MANY MEASUREMENTS COULD NOT BE MADE WITH EXISTING COMMERCIAL INSTRUMENTS, BECAUSE OF EXTREME VALUES TO BE MEASURED, HIGH ACCURACY AND FAST RESPONSE REQUIREMENTS, EXTREME ENVIRONMENTAL CONDITIONS AND OTHER SPECIAL FEATURES. THEREFORE, MANY STUDIES, RESEARCH, DEVELOPMENTS, MODIFICATIONS AND EVALUATIONS HAVE BEEN PERFORMED TO SECURE THE BEST INSTRUMENTS AND METHODS FOR MEASUREMENTS OR CALIBRATIONS, AND TOGETHER WITH THE SKILLFUL APPLICATION AND OPERATION OF THESE COMPLEX INSTRUMENT SYSTEMS THE TASK OF MEASUREMENTS HAS BEEN A VERY IMPOR-

TANT AND INFLUENTIAL PART OF THE AEROSPACE ACTIVITIES. IN ALL THESE EFFORTS THE SCALES HAVE PLAYED A VERY VITAL AND OUTSTANDING ROLE AND HELPED CONSIDERABLY TO PROVIDE ACCURATE AND RELIABLE MEASUREMENTS FOR ROCKET DEVELOPMENT. FOR MANY MEASUREMENTS THE USE OF SCALES HAS BEEN THE ONLY REASONABLE SOLUTION AND FOR MANY CALIBRATIONS SCALES HAVE BEEN THE WORKING STANDARD, WHICH IS THE BACKBONE OF MEASUREMENTS.

THE USE OF SCALES FOR DEVELOPMENT AND FIRING OF ROCKETS RANGES FROM WEIGHING A FEW MICROGRAMS FOR MATERIAL RESEARCH TO THE MEASUREMENT OF 12 MILLION LB. LOAD AT THE SATURN V LAUNCHING SITE. THE OLDEST AND VERY IMPORTANT WEIGHINGS IN ROCKETRY ARE CONNECTED WITH FLOWRATE, DENSITY, AND QUANTITY OF FUELS, THRUST OF ROCKET ENGINES, CENTER OF GRAVITY, AND THE LIFT-OFF WEIGHT OF MISSILES. OTHER IMPORTANT APPLICATIONS OF WEIGHING SYSTEMS ARE IN THE FIELD OF CALIBRATING VARIOUS EQUIPMENT AND INSTRUMENTS, ESPECIALLY PRESSURE GAGES. SOME INSTRUMENTS EVEN USE FOR MEASUREMENT A BUILT IN SCALE IN FORM OF LEVERS OR OTHER FORCE BALANCE PRINCIPLES. FURTHER THE SCALES AND LOAD CELLS ARE USED FOR DETERMINING WEIGHT, FORCE, STRUCTURAL LOADING, STRESS, AND TORQUE IN SHOPS AND AT TEST STANDS; MONITORING LOAD AND FORCE IN STAGE TRANSFER ON TRUCKS,

BARGES OR IN AIRPLANES; WEIGHING THE RATE OF EVAPORATION ON CERTAIN MATERIALS UNDER ULTRA-HIGH VACUUM WHICH SIMULATES SPACE CONDITIONS; MEASURING THRUST VECTOR; AND ROLL FORCES IN STATIC TESTING; AND FOR MANY OTHER APPLICATIONS.

BASED ON MY 26 YEARS ACTIVITIES IN INSTRUMENT DEVELOPMENT AND MY CONTACTS WITH MANY AEROSPACE AGENCIES AND COMPANIES I CAN ASSURE YOU THAT THE SCALE HAS BEEN VERY ESSENTIAL AND BENEFICIAL IN MISSILE AND SPACE ACTIVITIES NOT ONLY FOR WEIGHING OR FORCE MEASUREMENTS, BUT ALSO FOR MEASURING OTHER PARAMETERS EITHER WITH SCALES DIRECTLY OR BY USING SCALES FOR CALIBRATION OF OTHER INSTRUMENTS AND DEVICES.

I WILL NOW DISCUSS IN MORE DETAILS SOME SCALE APPLICATIONS WHICH REQUIRED MOST EFFORTS AND IMPROVEMENTS AND SOME NEW OR UNUSUAL SYSTEMS. I WILL INCLUDE A LOT ABOUT OUR WORK IN PEENEMUENDE, GERMANY, WHERE WE HAD VERY EXTENSIVE USE OF SCALES IN THE EARLY YEARS OF ROCKET DEVELOPMENT WHEN SCALES WERE ACCURATE AND RELIABLE WHILE MANY OTHER INSTRUMENTS WERE NOT YET USEABLE OR ACCURATE ENOUGH.

FIRST, THE FLOWRATE OF FUELS WHICH IS A VERY IMPORTANT MEASUREMENT IN THE DEVELOPMENT OF ROCKET ENGINES AND PROPULSION SYSTEMS. THE RATE OF FUEL CONSUMPTION IN LB/SEC. DETERMINES THE EFFICIENCY OR SPECIFIC IMPULSE OF THE ROCKET ENGINE AND THE MIXTURE RATIO OF THE TWO FUELS MUST BE A CERTAIN VALUE FOR BEST EFFICIENCY OF THE ENGINES.

BACK IN 1939 WE USED MECHANICAL SCALES FOR MOST FLOW-RATE MEASUREMENTS. BALL SHAPED FUEL TANKS WERE MOUNTED ON THE PLATFORM OF MECHANICAL SCALES. THE TANKS WERE PRESSURIZED WITH COMPRESSED AIR OR NITROGEN GAS, WHICH FORCED THE FUEL THROUGH A FUEL LINE INTO THE COMBUSTION CHAMBER. THE V2 COMBUSTION CHAMBER CONSUMED IN ONE FIRING OF ABOUT ONE MINUTE SOME FIVE METRIC TONS OR 11,000 LB. OF FUEL AND ABOUT THE SAME AMOUNT OF LIQUID OXYGEN. IN ROCKET TESTING ALL MEASUREMENTS HAVE TO BE RECORDED AND WE USED FILM CAMERAS TO RECORD THE DIAL OF THE SCALES AND FOR DUPLICATE RECORDING THE POSITION OF THE SCALE LEVER WAS RECORDED WITH A LIGHT BEAM, MOVING ON PHOTOGRAPHIC PAPER, SIMILAR TO THE OPTICAL RECORDING SYSTEM OF AN OSCILLOGRAPH. THE ACCURACY OF THE SCALES WAS BETTER THAN .1%, BUT THE FUEL LINE BETWEEN TANK AND COMBUSTION CHAMBER WAS ALWAYS A SOURCE OF ERROR OR

UNCERTAINTY SINCE IT PREVENTS FREE MOVEMENT OF THE SCALE PLATFORM. WE USED THE DIFFERENCE OF TWO SCALE READINGS TO DETERMINE THE FUEL CONSUMPTION IN A CERTAIN TIME, OR FLOWRATE AND THIS REDUCED SOME OF THE ERROR FROM THE DRAIN LINE BUT NOT ALL, SINCE THE PLATFORM OF THE SCALE MOVED BETWEEN THE TWO READINGS. WE TRIED TO KEEP THIS ERROR SMALL BY MAKING THE LINE AS FLEXIBLE AS POSSIBLE, USING LONG LINES, ELBOWS IN THE LINE, AND BELLOWS NEAR THE TANK AND NEAR THE COMBUSTION CHAMBER, OUR BELLOWS ARRANGEMENTS WERE SIMILAR TO THE THREE HINGE-JOINT BELLOWS, NOW COMMERCIALLY AVAILABLE.

ANOTHER SOURCE OF ERROR IN FLOWRATE MEASUREMENTS BY WEIGHING WITH SCALES WAS THE WEIGHT OF COMPRESSED GAS, ADDED TO THE TANKS WHILE TAKING FUELS OUT. WE MADE A CORRECTION OF THE SCALE READINGS, ADDING THE WEIGHT OF THE ADDED GAS WHICH WAS DETERMINED BY MEASURING THE PRESSURE AND TEMPERATURE CHANGE IN THE GAS SUPPLY BOTTLE THIS METHOD GAVE AN ACCURATE CORRECTION FOR THE WEIGHT OF GAS, ADDED TO THE FUEL TANKS, BUT IN LIQUID OXYGEN SOME OF THE GAS CONDENSED INTO THE LIQUID OXYGEN AND WAS PART OF THE FLOWRATE WHICH MEANS THE FLOWRATE MEASUREMENT WAS WRONG IF THE WEIGHT OF ALL ADDED GAS WAS ADDED TO THE DIFFERENCE IN SCALE READINGS. THIS ERROR WAS

AS MUCH AS 5% IN SOME INSTANCES BUT AFTER SOME EXPERIENCE IT HAS BEEN REDUCED TO NEGLIGIBLE VALUES IN MOST CASES.

WHEN WE STARTED TO TEST ENTIRE MISSILE SYSTEMS, WE COULD NOT WEIGHT INDIVIDUAL FUEL TANKS ANYMORE, BECAUSE THE CENTER SECTION OF THE ROCKET CONTAINED BOTH FUEL TANKS. REALIZING THIS WE HAD ALREADY STARTED A PROGRAM TO DEVELOP FLOWMETERS AND LEVEL GAGES IN ORDER TO GET FLOWRATE MEASUREMENTS FOR BOTH FUELS INDIVIDUALLY, BUT IT TOOK MANY YEARS BEFORE THESE INSTRUMENTS BECAME ACCURATE AND RELIABLE. ON THE OTHER HAND THE SCALE WAS CONSIDERED THE MOST RELIABLE INSTRUMENT, AND THEREFORE, THE TEST STAND FOR THE FIRST V2 MISSILE SYSTEMS HAD A MECHANICAL SCALE SYSTEM BUILT IN THE FRAMEWORK OF THE TEST STAND TO CHECK THE RESULTS FROM LEVEL GAGES AND FLOWMETERS. THIS SCALE WAS A SPECIAL DESIGN WITH A DOUBLE KNIFE EDGE FOR MEASURING DOWNWARD AND UPWARD FORCES. BEFORE THE TEST, THE SCALE MEASURED DOWNWARD FORCES COMPRISED BY THE WEIGHT OF THE HARDWARE OF THE MISSILE, THE WEIGHT OF THE FUELS AND THE WEIGHT OF THE PRESSURIZING GAS, WHICH WAS IN THIS CASE INCLUDED IN THE WEIGHING SINCE THE GAS TANK WAS PART OF THE MISSILE. WHEN THE COMBUSTION CHAMBER WAS FIRED AND PRODUCED A THRUST MORE THAN TWICE AS MUCH AS THE WEIGHT, THE SCALE DID MEASURE UPWARD FORCES, CONSISTING OF THRUST MINUS THE WEIGHT, MENTIONED ABOVE. **NATURALLY** IT WAS

DIFFICULT TO ANALYZE THE SCALE READINGS COMPOSED OF SO MANY COMPONENTS. HOWEVER, THE WEIGHT BEFORE AND AFTER THE TEST GAVE CLEARLY THE TOTAL WEIGHT OF THE TWO PROPELLANTS CONSUMED DURING THE TEST. THE AMOUNT OF THE CONSUMED ALCOHOL COULD BE DETERMINED BY WEIGHING THE AMOUNT FILLED IN AND WEIGHING THE AMOUNT LEFT OVER. THE DIFFERENCE BETWEEN THE TOTAL PROPELLANT WEIGHT AND THE ALCOHOL WEIGHT THEN GAVE THE AMOUNT OF LIQUID OXYGEN CONSUMED. THE COMBUSTION CHAMBER PRESSURE AND EFFECTIVE AREA OF THE COMBUSTION CHAMBER WAS A MEASURE OF THE THRUST AND IT GAVE ALSO THE TIMES FOR BUILD-UP, CONSTANT FLOW, AND SHUT-DOWN OF THE FLOW, WHICH PERMITTED TO DETERMINE THE FLOWRATE DURING THE CONSTANT COMBUSTION PERIOD FROM THE TOTAL FUEL CONSUMPTION, DETERMINED AS DESCRIBED ABOVE. THIS MEANS THERE WERE SEVERAL CROSS CHECKS, WHICH PERMITTED TO DETERMINE THE INDIVIDUAL VALUES, AND THE ACCURAC INCREASED CONSIDERABLY WITH TIME AND EXPERIENCE.

AFTER FLOWMETERS AND LEVEL GAGES BECAME MORE ACCURATE AND RELIABLE, WE GOT GOOD AGREEMENT OF THOSE RESULTS WITH THE RESULTS OBTAINED BY WEIGHING AND SUCH MULTIPLE MEASUREMENTS INCREASED THE ACCURACY OF FLOWRATE MEASUREMENTS CONSIDERABLY.

WHEN FLOWMETERS AND LEVEL GAGES BECAME FAIRLY ACCURATE AND RELIABLE, WE USED THEM ALSO AT ENGINE TEST STANDS WITH INDIVIDUAL TANKS AND AT PUMP TEST STANDS. HOWEVER, THE SCALES WERE NEVER ABANDONED BUT USED IN ADDITION TO FLOWMETERS AND LEVEL GAGES TO CHECK THEIR RESULTS, AND THE SCALES GAVE THE MOST RELIABLE DATA FOR THE FLOWRATE MEASUREMENTS IN PEENEMUENDE.

IN THIS COUNTRY, WE STARTED WITH SCALES TOO, BUT WITH INCREASING SIZE OF MISSILES WE HAD TO USE FLOWMETERS AND LEVEL GAGES FOR FLOWRATE MEASUREMENTS. HOWEVER, THIS DID NOT ELIMINATE THE SCALES SINCE FLOWMETERS, LEVEL GAGES, AND THE CAPACITY OF THE FUEL TANKS MUST BE CALIBRATED WITH SCALES. WE ALSO USE SCALES FOR DOUBLE CHECKS WHEREVER WE CAN AND THERE ARE STILL MANY SCALES OR OTHER WEIGHING SYSTEMS IN USE FOR FLOWRATE MEASUREMENTS AT THE DIFFERENT GOVERNMENT AGENCIES AND PRIVATE COMPANIES WORKING ON THE DEVELOPMENT OF MISSILES AND ROCKETS.

FOR FLOWMETER CALIBRATIONS THE MECHANICAL SCALE HAS BEEN USED EXTENSIVELY AS CALIBRATION STANDARD IN PEENEMUENDE AND IN THE UNITED STATES. WITH INCREASING

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ACCURACY AND RELIABILITY OF LEVEL GAGES, HOWEVER, SOME FLOWMETER CALIBRATION STANDS STARTED TO USE LEVEL GAGES AS A CALIBRATION STANDARD, AND ACTUALLY THE LEVEL GAGE IS A MORE DIRECT CALIBRATION INSTRUMENT FOR VOLUMETRIC FLOWMETERS. THE TURBINE FLOWMETER HAS BECOME A VERY ACCURATE AND RELIABLE VOLUMETRIC FLOWMETER AND ITS CALIBRATION WITH LEVEL GAGES BECAME QUITE COMMON IN THE ENTIRE MISSILE FIELD. HOWEVER, WHEN LIQUID HYDROGEN BECAME A FUEL IN ROCKETS THE TURBINE FLOWMETERS BECAME LESS SATISFACTORY, BECAUSE LIQUID HYDROGEN IS FIFTEEN TIMES LIGHTER THAN WATER OR FIFTEEN GALLONS OF LIQUID HYDROGEN WEIGH AS MUCH AS ONE GALLON OF WATER. ON THE OTHER HAND, THE MASS OF FUEL, NOT THE VOLUME DETERMINES THE SPECIFIC IMPULSE OF ROCKET ENGINES AND THEREFORE, GREAT EFFORT HAS BEEN MADE DURING THE LAST TEN YEARS TO DEVELOP MASS FLOWMETERS. FOR CALIBRATION OF MASS FLOWMETERS, HOWEVER, THE SCALE IS AGAIN THE BEST STANDARD INSTRUMENT.

IN 1951 WE STARTED A CONTRACT WITH WYLE LABORATORIES TO DEVELOP AND TEST LIQUID HYDROGEN MASS FLOWMETERS AND WE DESIGNED WITH WYLE LABORATORIES A CALIBRATION STAND WHICH ELIMINATED ALL PAST SHORTCOMINGS INCLUDING

LINE EFFECT, AND GAS COMPENSATION. THE HEART OF THIS CALIBRATION STAND IS AGAIN A MECHANICAL SCALE. AN INSULATED TANK WITH LIQUID HYDROGEN IS ON THE PLATFORM OF THE SCALE. AT THE START OF THE CALIBRATION THE FLOWRATE IS REGULATED TO THE DESIRED VALUE AND AFTER CONSTANT FLOWRATE IS ACHIEVED THE SCALE OPERATES A CAPACITIVE SWITCH, WHICH STARTS TIMERS AND FLOWMETER READOUT INSTRUMENTS. THEN DEAD WEIGHTS ARE LOWERED ONTO THE PLATFORM OF THE SCALE AND WHEN THE WEIGHT OF LIQUID HYDROGEN ~~FUEL~~, USED FOR THE CALIBRATION, HAS REACHED THE SAME VALUE AS THE WEIGHT OF THE DEAD WEIGHTS, THE SCALE GOES THROUGH THE SAME PRESET SWITCH POSITION AGAIN AND THE SWITCH STOPS TIMER AND READOUT INSTRUMENTS OF THE FLOWMETER. THIS MEANS THAT BOTH READINGS FOR THE DIFFERENCE OF FUEL ARE MADE AT THE SAME PLATFORM POSITION OF THE SCALE, PRACTICALLY ELIMINATING ERRORS, CAUSED BY THE SUCTION LINE. THE CONTAINERS FOR THE COMPRESSED GAS ARE ALSO ON THE PLATFORM OF THE SCALE ELIMINATING THE NEED TO COMPENSATE FOR THE GAS WEIGHT. THE ACCURACY OF THIS CALIBRATION STAND IS WITHIN .05% AND I BELIEVE WE DESIGNED THERE WITH WYLE LABORATORIES ONE OF THE MOST ADVANCED LIQUID HYDROGEN MASS FLOWMETER CALIBRATION STANDS. AGAIN A SCALE IS THE STANDARD INSTRUMENT.

ANOTHER UNUSUAL WEIGHING SYSTEM WAS DEVELOPED FOR LIQUID HYDROGEN FLOWRATE MEASUREMENTS AT THE TEST STAND. WE USED LOAD CELLS TO WEIGH THE TANK WITH THE LIQUID HYDROGEN, BUT THE TANK WEIGHT WAS ABOUT 10 TIMES THE WEIGHT OF THE HYDROGEN WHICH IS NOT A VERY FAVORABLE SITUATION FOR ACCURATE MEASUREMENTS. THEREFORE, WE ADDED A SO-CALLED INTERNAL WEIGHING SYSTEM. A NUMBER OF 6' LONG 6" DIAMETER TUBES, CLOSED AT THE END AND EVACUATED, ARE INTERCONNECTED AND HANG ON A WEIGHING SYSTEM MOUNTED ABOVE THE TANK. A LEVER, TARE WEIGH, CALIBRATION WEIGHTS AND A LOAD CELL ARE THE MAIN COMPONENTS OF THIS WEIGHING SYSTEM. THE CHAIN OF TUBES IS IN THE TANK AND WHEN THE TANK IS FILLED WITH LIQUID HYDROGEN THE BUOYANCY DECREASES THE WEIGHT OF THE TUBES. THUS, THE WEIGHT OF THE TUBES OR THE BUOYANT FORCE OF THE HYDROGEN IS A MEASURE OF THE AMOUNT OF HYDROGEN IN THE TANK.

FOR LEVEL GAGE CALIBRATION, SCALES HAVE BEEN USED ALMOST EXCLUSIVELY. A VERY ACCURATE METHOD IS TO DRAIN IN 20 TO 30 STEPS WATER FROM THE TANK INTO A BARREL ON THE PLATFORM OF A SCALE AND WEIGH IT. A VALVE AT THE END OF THE DRAIN LINE IS CLOSED BY SWITCHES OF THE DISCRETE LIQUID LEVEL GAGES, WHEN THE LEVEL PASSES THAT LEVEL SWITCH OR BY HAND OPERATED PUSH BUTTONS WHEN THE BARREL IS FULL. SIZE OF BARREL AND SCALE ARE DETERMINED BY THE SIZE OF THE TANK TO BE CALIBRATED. HOWEVER, WITH THE STEADY INCREASING SIZE OF TANKS WE HAD TO CHANGE TO A FASTER METHOD. THE LATEST METHOD IS TO DRAIN CONTINUOUSLY THROUGH A POSITIVE DISPLACEMENT FLOWMETER, WHICH IS THE TYPE OF METER USED AT GAS STATIONS. THIS METER IS CALIBRATED BEFORE USING LEVEL GAGES OR PROVER TANKS WHICH HAD BEEN CALIBRATED BY DRAINING WATER IN THE BARRELS ON THE SCALE AS DESCRIBED ABOVE. THE PROVER TANK IS A LARGE MEASURING TANK WITH SMALL CONTAINERS CONNECTED ON TOP AND BOTTOM FOR LIQUIDS, USED DURING THE START AND STOP PROCEDURES.

THE FILLING OF FUEL TANKS WAS ORIGINALLY DETERMINED WITH SCALES TOO. LATER WE USED LEVEL GAGES FOR FILLING CONTROL BUT AGAIN THE CAPACITY OF THE TANKS HAD

TO BE DETERMINED WITH SCALES. DURING MASS PRODUCTION OF THE V2 MORE THAN 10,000 FUEL TANKS WERE CALIBRATED BY FILLING THEM WITH WATER AND WEIGHING THEM WITH MECHANICAL SCALES. THE ACCURACY WAS .1% OR BETTER. IN THIS COUNTRY THE CAPACITY OF THE TANKS FOR ALL REDSTONE AND JUPITER MISSILES WERE ALSO DETERMINED WITH SCALES. NOW IN THE SATURN MISSILES THE TANKS ARE TOO BIG AND THEY ARE CALIBRATED WITH POSITIVE DISPLACEMENT FLOWMETERS AS DESCRIBED BEFORE, OR WITH OTHER VOLUMETRIC METHODS, AND MOSTLY SCALES ARE USED TO DETERMINE THE RESPECTIVE VOLUMES.

ALL THESE VOLUMETRIC QUANTITY MEASUREMENTS WITH LEVEL GAGES, PROVER TANKS, ETC., REQUIRE THAT THE DENSITY OF THE LIQUID IS KNOWN PRECISELY. THE DENSITY MEASUREMENT ON STORABLE PROPELLANTS IS MADE WITH SCALES IN A STRAIGHT FORWARD FASHION AT THE TEST STANDS AND IN CHEMISTRY LABS. WITH CRYOGENIC FUELS LIKE LIQUID OXYGEN AND LIQUID HYDROGEN THINGS ARE MORE COMPLICATED. THE HANDBOOKS OR INTERNATIONAL CRITICAL TABLES GIVE ACCURATE DENSITY VALUES FOR LIQUIFIED GASES AS FUNCTION OF PRESSURE AND TEMPERATURE. HOWEVER, WE FOUND DUE TO COMBINED USE OF LEVEL GAGES AND WEIGHING SYSTEMS, THAT THE DENSITY OF LIQUID OXYGEN IN MISSILE TANKS DOES NOT AGREE WITH THE DATA IN HANDBOOKS. NATURALLY, THIS WAS A DISCOVERY WHICH HAD TO BE PROVEN WITH 100%

CERTAINTY AND WE SPEND QUITE SOME MONEY AND EFFORT TO DO SO. WE BUILT A PRECISION CALIBRATION STAND WHICH USES FIVE WEIGHING SYSTEMS TO WEIGH THE SAME TANK FILLED WITH LIQUID OXYGEN (FIGURE 1). THE ACCURACY OF MEASUREMENTS CAN BE INCREASED BY USING SEVERAL INSTRUMENTS TO MEASURE THE SAME PARAMETER. THE INCREASE OF ACCURACY BY MULTIPLE MEASUREMENTS GOES WITH THE SQUARE ROOT OF THE NUMBER OF MEASUREMENTS WHICH MEANS THE AVERAGE OF THE RESULTS FROM FOUR GOOD INSTRUMENTS IS TWICE AS ACCURATE AS WITH ONE INSTRUMENT. IN THE SCHEMATIC FIGURE OF THE PRECISION WEIGHING SYSTEM WE SEE A MECHNICAL SCALE ARRANGEMENT CARRYING THE OTHER WEIGHING SYSTEMS AND THE TANK.

ON THE PLATFORM OF THE SCALE ARE THREE HYDRAULIC LOAD CELLS AND HEAD ON WITH THE HYDRAULIC LOAD CELLS ARE THREE ELECTRONIC LOAD CELLS SUPPORTING A SPIDER. ON THE SPIDER HANGS THE MISSILE TANK WITH TWO TENSION LOAD CELLS IN SERIES. WE KNOW THE VOLUME OF THE TANK FROM PREVIOUS CALIBRATIONS AND WITH THIS PRECISION WEIGHING SYSTEM WE DETERMINED THAT THE DENSITY OF LIQUID OXYGEN IN MISSILE TANKS IS .6% LESS THAN THE DENSIT DATA IN HANDBOOKS. THEREFORE, WE STARTED A RESEARCH

CONTRACT TO DEVELOP A DENSITY MEASURING INSTRUMENT FOR FIELD USE. THESE DENSITOMETERS USE NUCLEAR RADIATION AND FOR TEST AND CALIBRATION OF THESE INSTRUMENTS WE NEEDED SCALES AGAIN. WE SUBMERGED A PIECE OF QUARTZ AS A PLUMET INTO THE LIQUID OXYGEN. THIS PLUMET WAS SUSPENDED BY A LABORATORY SCALE AND THE CHANGE OF WEIGHT DUE TO THE BUOYANCY OF THE LIQUID WAS MEASURED WITH THE SCALE. THE VOLUME OF THE QUARTZ HAD BEEN DETERMINED EXACTLY BY THE BUREAU OF STANDARDS AND THUS THE CHANGE IN WEIGHT AND THE VOLUME OF THE QUARTZ GAVE THE DENSITY OF LIQUID OXYGEN. THE SAME WAS DONE FOR LIQUID HYDROGEN AND WE ACTUALLY EXPECTED LARGER DEVIATIONS OF THE HANDBOOK DATA FROM REAL HYDROGEN DENSITY, BECAUSE HYDROGEN DENSITY CHANGES MUCH MORE WITH TEMPERATURE THAN LIQUID OXYGEN, BUT TO OUR SURPRISE WE FOUND THAT THE LIQUID HYDROGEN DENSITY AGREED MUCH BETER WITH THE HANDBOOK DATA. THE REASON FOR THIS IS THE FACT THAT ALL OUR LIQUID HYDROGEN TANKS ARE WELL INSULATED, MOSTLY VACUUM JACKETED WHICH MEANS DOUBLE WALL WITH VACUUM BETWEEN THE WALLS LIKE THE THERMOS FLASKS USEI IN LABORATORIES WHERE THE HANDBOOK DATA ARE DETERMINED. LIQUID OXYGEN TANKS ARE NOT TEMPERATURE INSULATED AND THE HIGHER HEAT INFLUX CAUSES BUBBLING AND LOWER DENSITY THAN THE HANDBOOKS SAY.

THE LOW DENSITY OF LIQUID HYDROGEN AND THE INCREASING ACCURACY REQUIREMENTS OF MEASUREMENTS BROUGHT ANOTHER PROBLEM TO BE CONSIDERED IN WEIGHING, NAMELY THE BUOYANCY OF AIR. HEARING THE WORD BUOYANCY, ONE THINKS NORMALLY OF SWIMMING IN LIQUID. THE HUMAN BODY HAS ALMOST THE SAME AVERAGE DENSITY AS WATER, THEREFORE, THE BUOYANCY OF WATER MAKES US ALMOST WEIGHTLESS. ACTUALLY, THE BUOYANCY OF WATER IS BEING USED NOW TO STUDY THE EFFECT OF WEIGHTLESSNESS TO THE PERFORMANCE AND BEHAVIOR OF HUMAN BEINGS. ASTRONAUTS AND ENGINEERS, WEARING SPACE SUITS OR FACE MASKS, ARE COMPLETELY SUBMERGED IN WATER AND WITH SMALL PIECES OF METAL THEIR WEIGHT IS ADJUSTED TO THE BUOYANCY OF WATER.

THE BUOYANCY OF AIR IS MUCH SMALLER THAN THE BUOYANCY OF WATER AND MOSTLY NEGLECTED WHEN METAL OBJECTS ARE BEING WEIGHED, SINCE THE DENSITY OF METAL IS ABOUT 6,000 TIMES THAT OF AIR. WEIGHING WATER OR MISSILE FUELS HOWEVER, REQUIRES CORRECTIONS FOR AIR BUOYANCY. THE BUOYANCY EFFECT OF AIR IS .11% WHEN WEIGHING WATER; .10% FOR LIQUID OXYGEN AND .14% FOR ALCOHOL OR HYDROCARBON FUELS. FOR LIQUID HYDROGEN THE BUOYANCY OF AIR IS 1.5% AND CAN BE MUCH MORE WHEN LIQUID HYDROGEN

STARTS BOILING. THESE FIGURES ARE ACCURATE ENOUGH IN MOST CASES BUT FOR CALIBRATIONS OR WHEN HIGHEST ACCURACY IN WEIGHING IS NEEDED, WE MEASURE THE BAROMETRIC PRESSURE AND TEMPERATURE OF THE AIR TO DETERMINE THE AIR DENSITY AND ITS BUOYANCY EFFECT TO THE WEIGHT OF WATER, FUELS, OR EVEN METAL WEIGHTS WHICH ARE USED TO ADJUST AND CALIBRATE THE SCALES. WHEN WEIGHING MISSILES AT THE LAUNCHING SITE FOR DETERMINING THE LIFT-OFF WEIGHT, THE AIR BUOYANCY WAS ABOUT .13% FOR THE V2, REDSTONE AND JUPITER MISSILES WITH LIQUID OXYGEN AND HYDROCARBON FUEL IN THE FUEL TANKS. FOR SATURN MISSILES WITH LIQUID HYDROGEN IN THE UPPER STAGES, THE AIR BUOYANCY EFFECT IS HIGHER. THE SATURN MISSILES ARE NOT BEING WEIGHTED AT THE LAUNCHING SITE BECAUSE OF THE ENORMOUS COMPLEXITY. THE WEIGHT OF COMPONENTS ARE DETERMINED WITH SCALES IN THE SHOPS AND THE WEIGHT OF FUEL IS DETERMINED WITH OTHER METHODS AT THE LAUNCHING SITE. SOME OF THESE OTHER METHODS FOR FILLING CONTROL USE A WEIGHING PRINCIPLE TOO. THE AIR BUOYANCY FIGURE, HOWEVER, IS STILL NEEDED BECAUSE IT MUST BE ADDED TO THE THRUST. IT WAS ABOUT 4,500 LB. OR .3% FOR THE SATURN 1 MISSILES WHICH HAVE ALL BEEN FIRED NOW AND THE FINAL FIGURE FOR THE SATURN V MOON ROCKET HAS NOT YET BEEN DETERMINED.

THE LIFT-OFF WEIGHT OF MISSILES IS VERY IMPORTANT BECAUSE MASS AND FORCE DETERMINES THE ACCELERATION

WHICH INFLUENCES THE TARGETS OF BALLISTIC MISSILES OR THE PROPER TRAJECTORY TO GET IN ORBIT. IN PEENEMUENDE WE USED MECHANICAL SCALES FOR WEIGHING THE FIRST V2 MISSILES AT THE LAUNCHING SITE. THE V2 WAS STANDING FREE ON THE LAUNCHING TABLE ~~WHICH HAD FLAME DEFLECTORS LIKE AN INVERSED FUNNEL.~~ THE LAUNCHING TABLE WAS ON THE PLATFORM OF A MECHANICAL SCALE AND WE OBTAINED VERY ACCURATE VALUES FROM THIS SCALE. WE COMPARED THE SCALE READINGS WITH THE TOTAL WEIGHT OF ALL COMPONENTS, FUELS AND GASES AND WE DID OBTAIN AGREEMENTS OF ABOUT 50 KG IN 12,500 KG OR BETTER THAN 1/2%. OUR COMMANDING COLONEL DIDN'T BELIEVE THAT THE MECHANICAL SCALE WOULD SURVIVE A LAUNCHING AND SAID HE WOULD CHANGE HIS NAME TO MEIER IF THE SCALE SURVIVED. THE SCALE DID SURVIVE THE FIRINGS AND NEEDED ONLY MINOR ADJUSTMENTS OR REPAIRS BETWEEN FIRINGS. SO THE OBERST MEIER WAAGE BECAME QUITE FAMOUS AND USEFUL. THE MASS PRODUCED V2'S WERE NOT WEIGHED AT THE LAUNCHING SITE BUT THERE WAS A TIGHT CONTROL OF THE WEIGHTS OF ALL COMPONENTS AND FUELS.

IN THIS COUNTRY WE USED MECHANICAL SCALES AND LOAD CELLS FOR MEASURING THE LIFT-OFF WEIGHT OF REDSTONE AND JUPITER MISSILES. THERE WERE FOUR FIRING PADS,

TWO WITH MECHANICAL SCALES AND TWO WITH LOAD CELLS. THE RESULTS WERE ALSO COMPARED WITH THE TOTAL WEIGHT OF COMPONENTS AND FUELS AND THERE WERE MANY CONTROVERSIES BECAUSE THE MISSILES WERE NOT FREE ENOUGHT BUT THERE WERE TOO MANY CONNECTIONS TO STATIONARY GROUNDS FROM FUEL AND PRESSURE LINES, CABLES, ETC. ALSO, THE LOAD CELLS WERE SOMETIMES LOADED FOR MANY DAYS OR EVEN WEEKS AND SUFFERED ZERO SHIFTS. WE DESIGNED A SYSTEM WHICH WOULD KEEP THE LOAD CELLS BENEATH THE MISSILE UNLOADED AND WOULD RAISE THE LOAD CELLS AGAINST THE MISSILE AND LIFT IT SLIGHTLY, WHENEVER WEIGHT READINGS WOULD BE DESIRED, BUT THIS PROPOSAL WAS NOT ACCEPTED BECAUSE IT WAS UNDESIRABLE TO RAISE THE MISSILE. AS I MENTIONED BEFORE THE SATURN MISSILES ARE NOT BEING WEIGHED AT THE LAUNCHING SITE BECAUSE IT WOULD BE VERY COMPLEX, BUT AGAIN THERE IS A TIGHT CONTROL OF COMPONENTS AND FUEL WEIGHTS. A STUDY WAS MADE RECENTLY TO SEE IF WE SHOULD INTRODUCE WEIGHING SYSTEMS AGAIN, PROBABLY EVEN BETWEEN STAGES. IF A NEW MISSILE OR NEW LAUNCHING SITES AND PROCEDURES WILL BE DESIGNED, IT IS QUITE POSSIBLE THAT WEIGHING SYSTEMS WILL BE USED AGAIN FOR DETERMINING THE TOTAL LIFT-OFF WEIGHT AND THAT INTERSTAGE WEIGHING SYSTEMS WILL BE USED TO DETERMINE THE

WEIGHT OF INDIVIDUAL STAGES.

I MENTIONED BEFORE THAT THE LIFT-OFF WEIGHT OF MISSILES IS VERY IMPORTANT BECAUSE MASS AND FORCE DETERMINE THE BALLISTIC CHARACTERISTICS, BUT OTHERWISE I USED IN MY ENTIRE PRESENTATION THE WORD WEIGHT FOR EVERYTHING WE DETERMINED BY WEIGHING WITH SCALES. I DID THIS INTENTIONALLY TO AVOID CONFUSTION, BUT I HAVE GREAT RESERVATIONS ABOUT THE WORD WEIGHT AND I PUBLISHED IN THE OCTOBER 1960 ISSUE OF THE ISA JOURNAL AN ARTICLE ENTITLED "LET'S QUIT CONFUSING MASS WITH WEIGHT." EARLIER I PREPARED AN INTERNAL TECHNICAL REPORT ENTITLED "STANDARD PROCEDURE FOR USING UNITS OF MASS, WEIGHT, FORCE, PRESSURE, AND ACCELERATION."

THE WEIGHT IS DEFINED AS THE FORCE WITH WHICH THE GRAVITY OF THE EARTH ATTRACTS A BODY BUT UNFORTUNATELY THE WORD WEIGHT IS OFTEN USED FOR QUANTITY, ESPECIALLY IN MERCHANDIZING AND THEREFORE IT IS EASILY CONFUSED WITH MASS. THERE HAVE BEEN MANY HEATED DISCUSSIONS IF WEIGHT IS OR SHOULD BE MASS OR FORCE, BECAUSE THE WORD WEIGHT IS POORLY DEFINED AND CONSEQUENTLY MISUSED NOT ONLY IN EVERYDAY LANGUAGE BUT IN SCIENCE AND

ENGINEERING TOO. IF A PHYSICISTS SPEAKS ABOUT THE ATOMIC WEIGHT HE MEANS ACTUALLY MASS AND THERE ARE MANY OTHER SUCH CASES WHERE SCIENTIST AND ENGINEERS USE THE WORD WEIGHT FOR MASS. ~~EVEN THE NATIONAL BUREAU OF STANDARDS CALIBRATES WEIGHTS BY COMPARING WITH MASSES AND THE CERTIFIED DATA ARE MASS UNITS.~~ IN EVERYDAY LANGUAGE A MERCHANT WEIGHS SOMETHING FOR SALE AND MEANS QUANTITY OR MASS OF THE OBJECT. THE TRUCK WHICH CARRIES THE MERCHANDIZE MUST HAVE ENOUGH CAPACITY FOR A CERTAIN QUANTITY OR MASS AND IF A ONE TON TRUCK IS NEEDED THE TON IS A MASS UNIT, BUT THE TRUCK MUST ALSO BE STRONG ENOUGH TO CARRY THE LOAD OR WEIGHT AND IF THE CAR DEALER SELLS A ONE TON TRUCK THE TON IS IN THIS CASE A FORCE UNIT. RECENTLY, A GERMAN MAGAZINE ASKED A PROFESSOR AND DIRECTOR OF THE PHYSICS INSTITUTE AT THE UNIVERSITY OF FRANKFURT ABOUT HIS OPINION IN THIS PROBLEM AND THE PROFESSOR SAID THE BEST WOULD BE TO ELIMINATE THE WORD WEIGHT ALTOGETHER, BUT SINCE THIS WAS IMPOSSIBLE IT WOULD BE GOOD IF EVERYBODY INDICATES IF HE MEANS MASS OR FORCE WHEN HE TALKS ABOUT WEIGHT, BUT IT WOULD BE AN ABSOLUTE NECESSITY TO USE THE CORRECT UNITS OF MASS OR FORCE WHEN THE WEIGHT IS GIVEN IN NUMBERS. THE PROFESSOR THOUGHT

THE UNITS WOULD CLEARLY INDICATE IF THE NUMBER STANDS FOR MASS OR FORCE, BECAUSE IN GERMANY TODAY ALMOST EVERYBODY, INCLUDING WORKMEN AND TECHNICIANS, REQUIRED TO USE MASS, WEIGHT OR FORCE PROFESSIONALLY, DO USE KG FOR MASS AND KP (KILOPOND) FOR FORCE. THE KP WAS OFFICIALLY ADOPTED IN GERMANY AS UNIT OF FORCE ~~5 - 10 YEARS AGO AND~~ in 1939 by PTR (NBS equivalent) and gradually after WW II by universities, etc THE PROFESSOR DID NOT REALIZE THAT THE PEOPLE WHO WERE EDUCATED IN EUROPE ~~MORE THAN TEN YEARS AGO~~ before that time DO USE KG FOR MASS AND KG* AS FORCE, WHEREBY THEY OFTEN FORGET THE * AND WRITE KG FOR FORCE. AND EVEN WORSE IS THAT MOST ENGINEERS AND MANY OTHERS USE THE GRAVITATIONAL SYSTEM OF UNITS AND SAY KG IS THE UNIT OF FORCE AND KG/G OR KG · SEC^2/M IS A DERIVED UNIT OF MASS ALSO THE PROFESSOR DID NOT ENCOUNTER THAT THE PEOPLE USING ENGLISH UNITS DO OFTEN USE POUNDS FOR MASS AND FORCE. WE HAVE TO DEAL IN OUR DAILY WORK WITH METRIC AND ENGLISH UNITS AND WITH PEOPLE WHO WERE EDUCATED IN DIFFERENT COUNTRIES AND AT DIFFERENT TIMES WHICH MAKES IT ROUGH. DEFINITELY THE UNITS DO NOT INDICATE CLEARL IF THEY STAND FOR MASS OR FORCE.

IN MY ARTICLE "LET'S QUIT CONFUSING MASS WITH WEIGHT" I DO RECOMMEND TO USE LBM FOR POUND MASS, LBF FOR POUND FORCE, KG FOR KILOGRAM MASS, AND KP FOR KILOPOND FORCE. AS UNIT OF ACCELERATION I RECOMMEND TO USE THE STANDARD

GRAVITY G = 9.80665 M/SEC^2 OR 32.17398 FT/SEC^2 AND THEN THE NUMBERS ARE THE SAME FOR LBM AND LBF OR KG AND KP.

WHEN MORE COMPANIES AND AGENCIES BECAME ENGAGED IN ROCKET TECHNOLOGY, MANY EFFORTS WERE MADE TO DEFINE DIFFERENT TERMS UNIFORMLY AND ONE OF THESE DEFINITIONS WAS SPECIFIC IMPULSE WHICH IS THE THRUST OF THE ROCKET IN LBF DIVIDED BY FUEL CONSUMPTION OR MASS FLOWRATE IN LBM/SEC. UNFORTUNATELY THE CREATORS OF THIS DEFINITION DID NOT USE LBF FOR POUND FORCE AND LBM FOR POUND MASS BUT JUST LB FOR BOTH AND THEY DIVIDED LB BY LB/SEC WHICH RESULTED IN SEC. THIS IS STILL THE MEASURE OF SPECIFIC IMPULSE IN THIS COUNTRY AND FOR MORE THAN A YEAR A VEHEMENT FIGHT WAS GOING ON IN THE LETTERS TO THE EDITOR OF THE SPACE AND AERONAUTICS MAGAZINE and other publications or speeches ARGUING WHAT TO DO ABOUT THIS. THE LATEST NONSENSE I READ ~~THERE~~ WAS AN ARGUMENT THAT LBM IS A UNIT OF WEIGHT.

AT THE SAME TIME WHEN I WROTE MY TECHNICAL REPORT AND ISA PUBLICATION, THE GENERAL CONFERENCE OF WEIGHTS AND MEASURES IN PARIS ISSUED THE INTERNATIONAL SYSTEM OF UNITS CALLED SI FOR THE FRENCH NAME OF THE SYSTEM.

THE INTERNATIONAL SYSTEM OF UNITS ADOPTED SIX BASIC UNITS: METER, KILOGRAM, SECOND, DEGREES KELVIN, AMPERE, AND CANDELA AND AS SECONDARY UNITS IT ADOPTED NEWTON FOR FORCE AND WEIGHT. IT SAYS WEIGHT IS THE GRAVITATIONAL FORCE NOT MASS.

I HAD TO BE TOLERANT IN THE QUESTION OF USING METRIC UNITS OR ENGLISH UNITS SINCE BOTH HAVE BEEN USED AND WILL BE USED FOR A LONG TIME IN AEROSPACE TECHNOLOGY. HOWEVER, I AM A STRONG SUPPORTER OF THE MOVEMENT THAT ALL NATIONS USING ENGLISH UNITS NOW DO CHANGE TO THE METRIC SYSTEM IN A PLANNED FASHION AND THAT THE ENTIRE WORLD USES UNIFORMLY THE INTERNATIONAL SYSTEM OF UNITS (SI). THE NEWTON AS A UNIT OF FORCE OR WEIGHT IS RELATIVELY NEW TO ME AND MANY OF MY COLLEGUES ALSO, SINCE WE USED IT MAINLY IN PHYSICS, BUT NEVER IN ENGINEERING. BUT I THINK THAT THE ENTIRE SCIENTIFIC AND TECHNICAL COMMUNITY WILL GET ACCUSTOMED TO IT, JUST AS WE IMMIGRANTS GOT ACCUSTOMED TO THE POUND, GALLON, INCH AND ALL THE OTHER ENGLISH UNITS WHICH ARE FAR LESS PRACTICAL THAN METRIC UNITS.

THE USE OF UNIFORM UNITS ALL OVER THE WORLD IS VERY

ESSENTIAL. THE OTHER DAY A GERMAN COMPANY WAS REQUESTING BIDS FROM AMERICAN COMPANIES TO DESIGN A TEST FACILITY FOR A ROCKET WITH 5 MP THRUST. ONE OF THE AMERICAN COMPANIES DID NOT KNOW WHAT MP MEANS AND CALLED ME. I TOLD HIM THAT THE 5 MP ARE 5 MEGAPONDS, WHICH IS 5,000 KILOPONDS, OR 11,000 LBF. OR 49,000 NEWTON.

IN NEWS THE USE OF THE ENGLISH UNITS CAN BE CONFUSING. FOR EXAMPLE, WHEN GEMINI 8 WAS FIRED WALTER CRONKITE TALKED ABOUT MILES - ALTITUDE, AND THEN ADDED THESE ARE NAUTICAL MILES ~~WHICH ARE SO MANY~~ NOT STATUTE MILES. IN SPORTS NEWS THE REPORTERS ALSO HAVE OFTEN PROBLEMS TO TRANSLATE THE METERS INTO FEET OR YARDS OR KILOMETERS TO MILES. MAYBE INTERNATIONAL SPORTS NEWS ~~OR SPACE NEWS~~ WILL SOMEDAY BREAK THE ICE AND MAKE THE PUBLIC MORE ACQUAINTED AND AGREEABLE TO METRIC UNITS. THE BUREAU OF STANDARDS HAS ISSUED A MEMO IN 1964 AND NASA HAS ISSUED SEVERAL MEMOS IN RECENT YEARS, STATING THAT THE INTERNATIONAL SYSTEM OF UNITS WILL BE THE OFFICIAL SYSTEM OF UNITS. I PROPOSE THAT IN THIS COUNTRY EVERY WRITTEN REPORT, CATALOG, NEWSPAPER, ETC. USES TWO UNITS, ONE OF THEM IN PARENTHESIS LIKE THE WEIGHT OF 100 LBF (444 NEWTON), OR THE MASS OF 100 LBM

(45.4 KG). DON'T SAY 100 LBM (45.359237 KG) SINCE 100 LBM IS A ROUND FIGURE.

NOW A WEIGHING WHERE THE UNITS OF WEIGHT DON'T MATTER AND THIS IS THE DETERMINATION OF THE CENTER OF GRAVITY. THE CENTER OF GRAVITY IS VERY IMPORTANT FOR DYNAMIC FLIGHT CHARACTERISTICS OF MISSILES OR FOR SOME OTHER MOVING OBJECTS. IN MOST CASES LOAD CELLS ARE BEING USED FOR TWO, THREE, AND FOUR POINT WEIGHINGS. OFTEN ONLY THE LONGITUDINAL CENTER OF GRAVITY IS DETERMINED WITH TWO TENSION LOAD CELLS. WHEN THREE POINT WEIGHINGS ARE USED THE MISSILE RESTS ON A PLATFORM OR STRUCTURE WITH THREE COMPRESSION LOAD CELLS UNDERNEATH. FOR MORE EXACT LOCATION OF THE CENTER OF GRAVITY, ~~A FOUR POINT SYSTEM IS BEING USED~~. THE MISSILE RESTS IN RINGS ON TWO CROSSBARS EACH SUPPORTED BY TWO TENSION OR COMPRESSION LOAD CELLS. THE RINGS PROVIDE ALSO THE POSSIBILITY TO ROTATE THE ROCKET IN ORDER TO DETERMINE POSSIBLE CHANGES IN THE CENTER OF GRAVITY IN DIFFERENT PLANES. BESIDES ROCKETS THE CENTER OF GRAVITY MUST BE DETERMINED ON OTHER OBJECTS, FOR EXAMPLE, A RECENT TASK REQUIRED TO MEASURE THE CENTER OF GRAVITY ON A DROP TEST CAPSULE WHICH IS USED TO

STUDY THE EFFECT OF WEIGHTLESSNESS IN A 300 FT. FREE FALL LASTING 4.25 SEC. WE USED 100 LB. LOAD CELLS IN THE FOUR CORNERS OF A SQUARE PLATFORM AND OBTAINED GOOD RESULTS WITH A SENSITIVITY OF .002%.

THE THRUST OF ROCKET ENGINES HAS BEEN MEASURED WITH SCALES AT MOST TEST STANDS IN PEENEMUENDE. WE DID HAVE CAPACITIVE LOAD CELLS AND MAGNETO-STRICTIVE LOAD CELLS BUT WE USED THESE ONLY FOR QUALITATIVE STUDIES OF BUILD-UP, POSSIBEL OSCILLATIONS DURING THE STEADY STATE OR CONSTANT THRUST PERIOD AND THE DECAY AFTER CUTOFF. FOR QUANTITATIVE OR EXACT THRUST MEASUREMENTS DURING THE STEADY STATE PERIOD WE USED MECHANICAL SCALES, WHICH WERE AN INTEGRAL PART OF THE TEST STRUCTURE. WE OBTAINED ACCURATE VALUES WHEN THE FUEL LINES WERE FLEXIBLE ENOUGH. WE DID NOT HAVE STRAIN GAGE LOAD CELLS OR PRESSURE GAGES. AT THE END OF THE WAR WE HAD SEVERAL INTERROGATIONS BY ALLIED INTELLIGENCE SERVICES AND I WAS ASKED SEVERAL TIMES IF WE USED STRAIN GAGES BUT WE HAD NOT.

IN THIS COUNTRY THERE WERE AND PROBABLY STILL ARE SOME THRUST MEASUREMENTS WITH MECHANICAL SCALES BUT THE LARGE MAJORITY OF THRUST MEASUREMENTS ARE NOW BEING MADE WITH LOAD CELLS. I WAS PROBABLY THE STRONGEST

AND LONGEST OBJECTOR OF LOAD CELLS BECAUSE THE BEST STRAIN GAGE INSTRUMENTS IN THE LABORATORIES WERE NOT RELIABLE IN THE ROUGH ENVIRONMENT OF ROCKET TEST STANDS AND THE LAUNCHING SITE. HOWEVER, THE STRAIN GAGES HAVE MADE TREMENDOUS IMPROVEMENTS AND THE LOAD CELL INDUSTRY DEFINITELY DESERVES GREAT CREDIT AND COMMENDATION FOR THEIR ACCOMPLISHMENTS.

FOR CALIBRATING LOAD CELLS THE PROVING RINGS AND HYDRAULIC JACKS HAVE BEEN USED MOSTLY BUT THERE WERE AND STILL ARE ALSO TESTING MACHINES USING MECHANICAL SCALE SYSTEMS. LATELY MOST AGENCIES WITH ENOUGH MONEY AND JUSTIFICATIONS OBTAINED A DEAD WEIGHT LOAD CELL CALIBRATOR. THE NATIONAL BUREAU OF STANDARDS DEFINITELY GOT BEHIND IN LOAD CELL CALIBRATION CAPABILITY WITH THEIR 111,000 LB. DEAD WEIGHT MACHINE AND THEY EVEN COULD NOT CALIBRATE ALL DEAD WEIGHTS, NEEDED FOR THE DIFFERENT DEAD WEIGHT CALIBRATORS. HOWEVER, THE NATIONAL BUREAU OF STANDARDS HAS NOW PLACED IN OPERATION A BRAND NEW FACILITY WITH MODERN LOAD CELL CALIBRATION EQUIPMENT FOR DEAD WEIGHT CALIBRATIONS WITH THE RANGES OF 112,000 LB., 300,000 LB., AND 1,000,000 LB. THEY STILL USE THE WORD DEAD WEIGHT

AND THE UNIT LB. EVEN THOUGH THE BUREAU HAS OFFICIALLY ADOPTED THE INTERNATIONAL SYSTEM OF UNITS. WITH PROVING RINGS OR OTHER SECONDARY STANDARDS THEY CALIBRATE UP TO 12 MILLION POUNDS. THERE ARE SEVERAL OTHER DEAD WEIGHT CALIBRATORS WITH CAPACITIES OF A MILLION POUNDS OR MORE. WE HAVE THREE LOAD CELL CALIBRATORS WITH DEAD WEIGHTS IN THE RANGES UP TO 5,000, 50,000, AND 500,000 LB. THE 500,000 LB. CALIBRATOR HAS ALSO TEN 500,000 LB. PRECISION LOAD CELLS WHICH ARE USED IN PARALLEL TO CALIBRATE LOAD CELLS UP TO 5 MILLION POUNDS. THE ACCURACY OF THE DEAD WEIGHT CALIBRATORS IS .006% OR BETTER AND THE ACCURACY OF THE 5,000,000 LOAD CELL CALIBRATOR IS ABOUT .02%. TO INCREASE THE ACCURACY AND RELIABILITY OF THIS PART OF THE RANGE WE PLANNED TWO SETS OF TEN EACH 500,000 LB. LOAD CELLS IN SERIES. THE SECOND SET IS JUST BEING INSTALLED AND I CANNOT GIVE PERFORMANCE DATA YET.

AS FINAL ITEM I WOULD LIKE TO MENTION THE PRESSURE BALANCE WHICH WE DEVELOPED SOME 18 YEARS AGO WHEN WE WERE REQUESTED TO MEASURE ON A RAMJET NOZZLE A PRESSURE OF 200 PSI WITH AN ACCURACY OF .1 PSI. THERE WAS NO PRESSURE GAGE WHICH APPROACHED THIS ACCURACY OF 1 IN

2000 OR .05%, BUT WHEN I LEARNED THAT THIS PRESSURE IS ALWAYS BETWEEN 195 AND 205 PSI I REALIZED THAT I COULD MEASURE WITHIN .1 PSI USING A ±5 PSI DIFFERENTIAL PRESSURE GAGE IF I HAD AN ACCURATE REFERENCE PRESSURE OF 200 PSI. LOOKING FOR SUCH AN ACCURATE REFERENCE PRESSURE I CONCEIVED THE IDEA OF USING A SCALE AND WE DEVELOPED THE PRESSURE BALANCE SHOWN IN FIGURE 2. THE PRESSURE IS CONVERTED INTO FORCE BY A ROTATING PISTON AND THIS FORCE IS WEIGHED WITH A SCALE. COMPRESSED AIR OR NITROGEN GAS IS APPLIED ON TOP OF A CYLINDER AND INSIDE THE CYLINDER IS A ROTATING PISTON AND A LITTLE OIL ABOVE THE PISTON TO LUBRICATE AND SEAL. THE PRESSURE FORCES THE PISTON DOWN AGAINST THE BEAM OF THE SCALE THROUGH A THRUST PIVOT WHICH ASSURES GOOD SEATING AND SMOOTH ROTATION. THE EFFECTIVE AREA OF THE PISTON AND THE WEIGHT ON THE OTHER ARM OF THE SCALE DETERMINES THE PRESSURE. A VERY SENSITIVE NULL SWITCH OPERATES SOLENOID VALVES TO LET GAS IN OR OUT WHEN THE PRESSURE IS LOWER OR HIGHER THAN THE VALUE, CALLED FOR BY THE WEIGHTS.

WE FOUND OUT SOON THAT THIS PRESSURE BALANCE WAS AN EXCELLENT CALIBRATION STANDARD FOR PRESSURE GAGES AND

DEVELOPED IN A RESEARCH CONTRACT WITH AN INDUSTRIAL FIRM A PROGRAMMING DEVICE AND AN AUTOMATIC WEIGHT HANDLER WHICH CAN PUT ANY COMBINATION OF WEIGHTS ON THE SCALE REQUIRED TO REGULATE THE PRESSURE TO ANY VALUE BETWEEN 1 AND 6000 PSI IN STEPS OF 1 PSI USING 15 WEIGHTS IN A BINARY-DECIMAL CODED ARRANGEMENT. THE AUTOMATIC REGULATING SYSTEM WITH THE NULL SWITCH ON THE SCALE OPERATES THE SOLENOID VALVES AND REGULATES THE PRESSURE WHICH IS ASKED FOR BY THE PROGRAMMING DEVICE. THE PRESSURE BALANCE IS NOW BEING USED AS MOST FAVORED PRESSURE GAGE CALIBRATION STANDARD IN MANY AEROSPACE OPERATIONS. WE HAVE ABOUT 50 IN OPERATION AT MSFC.

IN OUR OWN LABORATORIES WE HAVE DEVELOPED AN AUTOMATIC IBM CARD PUNCH SYSTEM TO RECORD THE OUTPUT OF THE CALIBRATED PRESSURE TRANSDUCERS AND AS YOU SEE IN THE FOLLOING FILM THE CALIBRATION OF PRESSURE TRANSDUCERS GOES COMPLETELY AUTOMATIC AFTER THE PROPER PROGRAMMING DEVICE IS SET UP AND THE SYSTEM IS STARTED. AGAIN A SCALE IS THE HEART OF THIS AUTOMATIC PRESSURE CALIBRATION SYSTEM.

I HOPE THAT THESE EXAMPLES ILLUSTRATED THE IMPORTANT

ROLE OF SCALES IN DEVELOPMENT AND FIRING OF MISSILES AND SPACESHIPS, AND THAT YOU DO NOT MIND MY EXCURSION INTO THE SUBJECT OF UNITS. AS CONCLUSION OF MY PRESENTATION I WANT TO SHOW YOU A SHORT FILM ABOUT SOME OF MSFC'S ACTIVITIES, BUT SINCE I SPOKE HERE BECAUSE DR. VON BRAUN COULD NOT ACCEPT THE INVITATION OF THE NATIONAL SCALE MEN ASSOCIATION, I WOULD LIKE TO ADD HERE A SHORT STORY CONCERNING DR. VON BRAUN.

AT THE END OF THE WAR THE PEENEMUENDE GROUP MOVED SEVERAL TIMES AWAY FROM RUSSIAN AND AMERICAN ARMIES AND WAS FINALLY HIDING AT DIFFERENT PLACES IN SOUTHERN GERMANY UNTIL DR. VON BRAUN SENT HIS BROTHER TO THE AMERICAN TROOPS AND GAVE WORD TO THE AMERICAN INTELLIGENCE SERVICE, DISCLOSING WHERE ABOUT 500 KEY MEMBERS OF THE PEENEMUENDE GROUP WERE. THE U.S. INTELLIGENCE SERVICE GATHERED US AGAIN IN A STAFF BUILDING OF THE FORMER GERMAN ARMY IN GARMISCH-PARTENKIRCHEN NEAR THE BAVARIAN ALPS. AFTER ABOUT TWO MONTHS DR. VON BRAUN WAS TRANSFERRED TO MIDDLE GERMANY FOR TALKS WITH AMERICAN OFFICERS AND AFTER HE HAD LEFT I WENT TO HIS ROOM TO SEE IF HE HAD LEFT ANYTHING TO SMOKE, EAT, OR DRINK, SINCE THERE WAS A GREAT SHORTAGE IN THESE ITEMS BUT ALL I FOUND WAS WASTE PAPER, EXCEPT A SEVEN PAGE DRAFT OF A REPORT

WITH THE TITLE "SURVEY ABOUT THE PAST DEVELOPMENT OF THE LIQUID ROCKET IN GERMANY AND ITS PROSPECTS IN THE FUTURE." THE FUTURE PROSPECTS MENTIONED MANNED MULTISTAGE ROCKETS; SATELLITES; SPACE STATIONS; COMMUTING ROCKETS TO THE SPACE STATION; OUTER SPACE OBSERVATION OF OBJECTS AND EVENTS ON GROUND; WEATHER PREDICTIONS AND INFLUENCE OF WEATHER; TRIP TO THE MOON OR OTHER PLANETS; LONG DISTANCE PASSENGER ROCKETS COVERING THE DISTANCE FROM EUROPE TO AMERICA IN 40 MINUTES; ETC. I THOUGHT THEN THAT THIS WAS A DREAM, BUT YOU KNOW HOW MUCH OF IT IS TRUE TODAY, AND I AM SURE THAT SOME AGENCIES ARE WORKING ON MOST OF THOSE PARTS OF THE 1945 REPORT WHICH ARE NOT REALITY YET.