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CREW MEMBER INTERFACE WITH SPACE STATION FURNACE FACILITY

Martha B. Cash
Crew Systems Branch
NASA/Marshall Space Flight Center

Introduction

The Space Station Furnace Facility (SSFF) is a facility located in the International Space Station United States Laboratory (ISS US Lab) for materials research in the microgravity environment. The SSFF will accommodate basic research, commercial applications, and studies of phenomena of metals and alloys, electronic and photonic materials, and glasses and ceramics. To support this broad base of research requirements, the SSFF will operate, regulate, and support a variety of Experiment Modules (EMs). To meet station requirements concerning the microgravity level needed for experiments, station is providing an active vibration isolation system, and SSFF provides the interface.

SSFF physically consists of a Core Rack and two instrument racks (IRs) that occupy three adjacent ISS US Lab rack locations within the International Space Station (ISS). This generic SSFF configuration is shown in Figure L All SSFF racks are modified International Standard Payload Racks (ISPR). SSFF racks will have a 50% larger pass through area on the lower sides than ISPRs to accommodate the many rack to rack interconnections. The Instrument Racks are further modified with lowered floors and an additional removable panel (15” x 22”) on top of the rack for access if needed. The Core Rack shall contain all centralized Core subsystems and ISS subsystem equipment. The two Instrument Racks shall contain the distributed Core subsystem equipment, ISS subsystem equipment, and the EMs. The Core System. which includes the Core Rack, the IR structures, and subsystem components located in the IRs serves as the central control and management for the IRs and the EMs. The Core System receives the resources provided by the International Space Station (ISS) and modifies, allocates, and distributes these resources to meet the operational requirements of the furnaces. The Core System is able to support a total of four EMs, and can control, support, and activate/deactivate the operations of two EMs simultaneously. The IRs can be configured to house two small EMs or one tall vertical EM, and serve as the interface between the Core and the respective EM.

The Core ***Rack*** and an adjacent Instrument Rack **(containing one or more furnaces) will be delivered to the ISS in one** launch. This is Integrated Configuration One (IC1). The Core Rack and IR1 will be passive ***during transport*** in the Mini Pressurized Logistics Module (MPLM). Any subsequent EMs to operate within IR1 are installed on-orbit. The second IR (containing one or more furnaces) is delivered to ISS on a subsequent launch which will establish Integrated Configuration Two (IC2). **Additional integrated configurations will be established with the replacement** of EMs or Instrument Racks.

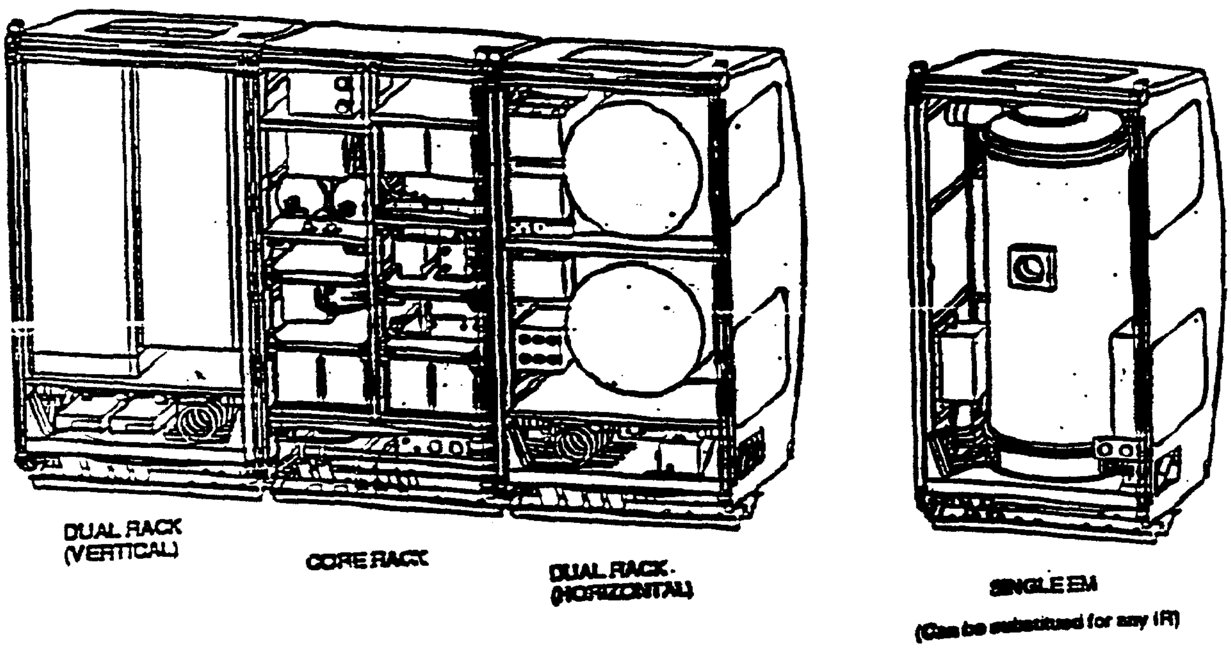

Figure 1. SSFF Generic Configuration

SSFF/Crew Interface
Initially, the physical layout, launch configuration, and basic functions of SSFF must be understood *in* order to identify crew interfaces necessary for operation. Crew time available is baselined at 90 crew hours per week for all payloads. Assuming that the Lab has 12 ISPRs, 6 ISPRs in the Attached Pressurized module, and 12 ISPRs in the Japanese Experiment Module, the result is about three crew hours per week per rack on average. This is a small number which must include installation, maintenance, and routine sample exchange. Therefore, SSFF has chosen a high degree of automation for most of its functions and considered the following critical crew interfaces in order for the facility to make efficient use of crew time Visual and reach envelopes, Operating forces, Crew and loose equipment restraints, Data displays and controls, Microgravity and the resulting Neutral Body Posture, General and task lighting, Tools, Fasteners, Connectors, Crew Safety, Workstations, Serviceability, and Labeling.

A brief description of some SSFF (based upon current configuration) related tasks which depend upon crew members are as follows: The Core Rack will be launched with all its components in place and six additional flight boxes intended for on orbit installation into the instrument racks. The Core Rack will be moved by the crew from the Logistics Module to its permanent operating location inside the Lab. After installing the Core Rack into position, the crew returns to the Logistics Module and transports Instrument Rack 1 (IR1) into the Lab and into position on the left hand side of the Core Rack. IR1 is launched with one Experiment Module (EM) already installed but requires the on orbit installation of four flight boxes. These must be removed from their bolted down launch position inside the Core Rack and placed in operational location in IR1; securing the fasteners and connectors of each &vice. The other two devices remain stowed in the Core Rack until the arrival of IR2, at which time the two remaining boxes will be installed in their operational position. The unattached harness cables must be restrained and all exposed connectors must be protected with covers, or attached to 'dummy' connectors. Volume constraint made restrained cables with covered connectors the selected option. Therefore, connector covers would have to be removed and stowed and the cable untethered prior to making any connection. ISS resource connections to the Core Rack and IRs must be performed by the crew. In order for the Core Rack to control EM(s) inside the IRs; all power, data, and gas connections from rack to rack must be done by the crew on orbit. Any configuration of an active rack isolation system demands that the IRs cannot remain attached to their pivots during operation, but instead must be attached to actuator shafts; which must be installed by the crew. Maintenance operations which require rotation of any one rack demands that either all rack to rack connections be dismantled or that all three racks are rotated out as one unit. A rotation of all three racks as one unit in O g is believed to be the easier of the two options. The racks must be latched together at the top and the IRs removed from actuator shafts and reinstalled upon their pivots as a minimum. Sample insertion and exchange in furnaces demand crew interface with SSFF faceplates, EMs (and associated connectors, tools, hoses, cables), and gloveboxes. Maintenance or upgrade activity depend upon the crew to complete. Some EMs may require command inputs from the crew via the Portable Computer System (PCS).

Approach
A high level task analysis titled SSFF-HETAG-01, "Space Station Furnace Facility Task Analysis-Gross", is provided to systematically identify and characterize major human interface issues and serve as a data source for SSFF-HER-01, "Human Engineering Requirements", test plans and procedures, and SSFF-HECTA-01, "Human Engineering Critical Task Analysis" The Gross Task Analysis gives a beginning point for decision making concerning mock up builds for human subject testing by examining the following subtasks: Lab site checkout, Logistics site checkout, Core and Instrument Rack installation, Core System activation, Nominal EM operations, Facility nominal shutdown, and Maintenance/Upgrade.

Crew interface requirements for SSFF were initially derived in the following manner: NASA-STD-3000, '"Man-Systems Integration Standards" is the original human factors requirements document which covers all aspects of crew-flight concerns; much information that does not apply to a furnace facility. A designer, whether for facility, experiment module. or orbital replaceable unit (ORU) would have to search through extraneous information and attempt to extract that which applied to their particular task. SSP 50005, "ISSA Flight Crew Integration Standards" is derived from NASA-STD-3000 and contains only requirements that pertain to Space Station. This is still not specific enough to help a designer of a furnace facility, an experiment module, or an ORU identify applicable requirements rapidly. Therefore, SSFF-HER-0 1, "Space Station Furnace Facility Human Engineering Requirements" is derived from the above two parent requirements documents and is also influenced by design, specific intent, and the Station Interface Control Document (ICD). SSFF-HER-01 is divided into three sections: Facility, Experiment Module, and ORU sections. A verification matrix is included with each section. This is to simplify the designer's task; i.e., a furnace designer would use the Experiment Module Section of SSFF-HER-01 for human factors requirements applicable to experiment modules.

SSFF-HECTA-01, "Space Station Furnace Facility Critical Task Analysis" (CTA) is an extension and elaboration of the "Gross Task Analysis" (GTA) in matrix format: step by step task description accompanied by applicable SSFF-HER-01 paragraph numbers, crew posture necessary, and notes (tools or not). The Critical Task Analysis can be used as an input to the Crew Procedures development process by systematically examining flight crew tasks which are critical to mission success. The task analysis begins with the Core Rack and the Instrument Rack installed in the Lab but not connected, proceed through interconnection of racks and ISS, sample loading and unloading, ORU changeout, and Rack rotation. The analysis ends with sample removal after the first increment of operation. This document is continuously updated with the cycle of design change and crew interface tests.

"Space Station Furnace Facility Human Engineering Development Test Plan", SSFF-HEDTP-01, presents tests to be performed with human subjects, program objectives, anticipated results, facility and hardware requirements, reference to CTA sections, lead time required, test dates, and required report dates. The following tests are documented for Phase I: Rack Face Plate Configurations, Avionics Air Coupling, Utility Interface Concepts, ISPR Lowered Floor, Electrical Connector Selection, Single Vs. Multiple Rack Rotation, ORU Changeout, Crew Interface Port Placement and Utilization, Glovebox Installation and Operation with Rack Rotation, Sample Port Location and size. For Phase II design: the following tests are documented: Active Rack Isolation System (ARIS), ORU Changeout. For Phase III design- Alternative ORU placement; ORU Changeouts are repeated, and EM/Glovebox protrusions.

Mock ups

A lot of effort was concentrated on building a mockup of ISS Lab envelope containing SSFF. A rigid material (4 x 8 foot sheets of 3/8 inch thick Styrofoam covered with paper), called Fome Core™ covers the wood frames forming the ceiling and opposite wall of SSFF envelope. A raised plywood floor represents racks that will be in that plane and the station stand off, with 'Z' plates (connects resources from station to racks) made of Fome Core. Three racks (not ISPR quality) are used to represent the Core Rack, IR1 and IR2. The cold plates, flight boxes, and EMs are constructed of Fome Core and installed inside the racks. Most of the cold plates and Gas Distribution System (GDS) mock ups can slide out of the Core Rack along with their contents. Initially, many devices were only Fome Core volumes until more could be learned about the device's exact dimensions. Real connectors, fasteners, and cables are mounted on devices that either have to be installed on orbit, or their failure rate suggests that maintenance operations will be necessary. Cables and hoses are represented by various sized tygon tubing. The degree of fidelity is greater in areas where there is known crew interface.

Many components of SSFF mock up changed during project development. For example, IR1 has contained a Fome Core mock up of a cylindrical furnace with the sample port in the front, a movable carousel, and wooden mock ups of the sample cartridges installed. Beside it was a larger cylindrical furnace with an excess port in the top, and attached side hinges which allowed it to be pulled straight out of the IR1 front and rotated to rest in a vertical position in front of the Core rack. These were replaced later with two rectangular vertical furnace mock ups with both sample ports in the front. IR2 contains two horizontal cradle-mounted furnaces, which are envelope representations only. All the avionics boxes in IR2 are mounted on slides which can be pulled out into the aisle. Two types of gloveboxes were constructed; flexible and rigid. The flexible version was constructed of canvass and Plexiglas. The rigid model was made of Fome Core and Plexiglas.

A mockup of the PCS with a "D" type connector to interface with the crew interface port (CIP) is provided. Velcro is placed on the instrument rack face plates for placement of the lap-top computer with the top of the monitor approximately four and one-half feet from the floor.

The three racks may be fixed together on orbit so that they rotate as one assembly, to avoid disconnections between the Core and the instrument racks. Some critical devices must be located in the back of the racks; either behind furnaces or other equipment. This may make rack rotation necessary several times during the removal/installation of these devices. In order to study this task, each rack is individually counterbalanced with a configuration of pulleys and weights, therefore, all three racks may be locked together at the top and rotated out as one unit, i.e., the whole unit is counterbalanced and will remain in whatever position is needed without any further restraints or attention. Additions or changes inside any rack alters the weight of the rack; counterbalancing is then dealt with by changing the weights in the pulley-weight configuration for that specific rack.

After the initial build, unexpected questions or configurations can be quickly investigated with this mockup which includes surrounding ISS envelope, boxes, lowered floor, shutoff valves, maintenance kill switch, crew interface port, connectors, racks, passthroughs and accesses, pull-out shelves, face plates, some cables and hoses, EMs, Gas Distribution Systems, station 'Z plate plus prototype connectors, and rotating (individual or ganged) counterbalanced racks.

Some crew interface issues had to be addressed before the comprehensive mockup described above was complete. Other tasks examined required the crew to be 'upside down' relative to the local vertical. In these tests, the racks were positioned horizontally with face plates up. Rack to rack interconnections could then be studied with subjects lying on top the rack plates with their heads at the bottom of the racks. This was the crew position most likely to be used for feeding cables through the rack side access panels for rack to rack connections. Mockup hardware was limited to the area of concern: i.e., the lowered floor, connectors, quick disconnects, tethered cables, labels, and a station 'Z' plate prototype for connecting rack to station resources. In another example, an Avionics Air issue concerning a flex hose connection within the one half inch clearance between the Core Rack and IR1&2 was mocked up with two racks, PVC pipe, flex hose, and a clamp, The two racks were positioned one-half inch apart, side-by-side, and face down in the floor. The rack-to-rack coupling was to be done through the access in the top of the instrument rack and through the side access cut-outs in both the instrument and Core racks. The whole SSFF envelope, detailed components in all three racks, etc. was not necessary to determine that the more space allowed between the solid portion of the air duct and the side access inside IR1, the easier the task of attaching the flex hose between the Core Rack and IR1 duct. Concerns about a box's connectors interfering with tool-hand clearances while securing its flange fasteners was answered with the Fome Core mockup of the box itself complete with real (not flight) connectors, fasteners, and actually using an allen wrench to release a fastener. Understanding the relationship of portions of SSFF configuration was greatly instrumental in building the comprehensive mock up.

Testing with Subjects

Anthropodemetric measuring of many subjects was done prior to testing in an effort to employ the abilities and limitations of the ISS physical dimensions range of 5th percentile (40 year old Japanese female) to 95th percentile (40 year old American male). Seven was the average number of subjects participating pertest and most were working on the SSFF project in various disciplines. Whether individual or group tests, the subjects were briefed as to the hardware description, order of expected tasks, and test objective. The reminder that these tasks must be performed in O g was enforced as much as possible. Where applicable, an 'ergo-chair' was used, which held a person as close as possible to the neutral body position experienced in O g. The test conductor followed a step-by-step checklist of each specific task, which was part of the written test procedure. Comments and suggestions made by the subjects during testing was recorded by the test conductor. Subjects usually completed a questionnaire at the end of a test session. A group test was held for Phase III design - Alternative ORU placement only. For this test, a group of four subjects were allowed to discuss the problem among themselves and physically move shelves and boxes within the racks until they were all satisfied. The physical configuration agreed upon by the group was then recorded. With a mock up in place and an understanding of the required crew task involving the hardware; specific test plans and test procedures for each area investigated were developed.

Evaluation

Methodologies range from pure observation, analysis, questionnaries, to ranking, or some combination of these methods. For example, SSFF is required to maintain the rack face plates in place during operation in order to contain CO_2 for fire suppression. The face plates must also meet the launch load requirements and provide noise attenuation. These requirements complicate crew tasks such as maintenance and servicing by limiting SSFF adjacent rack access, handrail interference, visual, and reach envelopes because the face plates must be opened or removed to perform the tasks mentioned. Although frequent need for the crew to access SSFF racks is not expected, known tasks such as gas bottle change-out prompted the investigation of different face plate configurations through a mock up and test subjects to attempt to arrive at the most 'user-friendly' solution that still allows the face plates to meet more critical requirements. Prior to the mock up demonstration, a preliminary matrix was built with other disciplines participating, listing the requirements of the rack face plates, Goals were associated with each requirement. Symbols indicated each requirement and its intended goal as well as overlapping of unrelated requirements through their goals. Numbers replaced the symbols associated with each requirement based upon a scale of 5 being very important and 1 being hardy important. All values assigned to each requirement were added and then normalized to give every requirement a weight, Four face plate designs were evaluated using the computed weights for the agreed upon requirements. In addition to this described preliminary analysis, seven subjects participated using a test procedure of step-by-step motions outlined for each design configuration. Motion was constrained by the use of an 'ergo chair' to mimic the neutral body posture characteristic of O g. Individuals were timed with a stop watch for the time difference required between the designs as they performed the tasks. The time required to perform the tasks was averaged for each faceplate design. Subjects were asked to complete a questionnaire ranking each design according to effort associated with selected crew interface requirements. Also, their comments were noted on their procedure sheet by the test conductor. The subjects picked the same configuration as the preliminary analysis had indicated to be the 'best design', with the ranking of the other designs varying.

In other instances, the whole range of subject sizes, i.e., 5th percentile (smallest) to 95th percentile (largest); would express the same opinion. This was true with the on-orbit installation testing. IR1 was rotated into the aisle at about the 80' position with its back panel removed. The four flight boxes launched bolted inside the Core Rack were removed and installed into IR1 from the back of the rotated rack. The flange fasteners on the Peltier Pulser and the FSCU (Furnace Signal Conditioning Unit) opposite the operator's position could not be seen or reached. The problem existed for the entire body size range of subjects. Immediate comments such as "I can not see the fasteners," or "I can not reach behind the box." were made. In other instances, no problems were detected, and favorable comments would be common. This was true with the slide out shelves on which the stowed for launch devices were mounted as well as for the Gas Distribution System (GDS) configuration. The quick disconnects used for the GDS integration testing received no comment because the subjects were able to make the connection. User comments are the best source of ideas since they may reveal why particular errors are occurring. Comments are collected while the user is working, since impressions given after a task is complete are often sketchy. The group testing relied upon their internal discussion and agreement upon device placement, The test reports, which include the evaluations, must be distributed to the designers as shown in Figure 2.

Results

The crew interface organization and flow of work for SSFF is best described in Figure 2. Notable outcomes from this iterative cycle include, but are not limited to:
The fidelity of SSFF hardware features pertinent to the SSFF trainer were identified through the use of the crew interface mock up and testing. More information is available concerning task sequence, completion times, and rack positions (rotated or not). This all feeds directly into crew procedures which will be developed much later in the project. Details such as clearance problems, special tools or modifications concerning ISS provided tools become known. Verification and clarification of many human factors requirements were accomplished as well as configuration feasibility of selected features SSFF which involve human interface. Launch configuration modifications were suggested as a result of problems encountered during on-orbit installation procedures. Misconceptions among various disciplines concerning the physical layout are quickly brought out in tests.

Conclusion

Incorporating crew interface issues early into a design demands an iterative process of design, evaluation, and test with the test results feeding back into design. This can be conceived as slowing down the design process or levying extraneous requirements onto the design. However, building simulated or informal prototypes actually gives a project something tangible for others to see, and stimulates thought and progress. A detailed understanding of the &sign and the necessary crew tasks has enhanced matching the intent of crew interface requirements with the design. Once a comprehensive mockup of SSFF was in place, unexpected questions, design changes, and 'what if scenarios could be tested and produce results quickly. This effort should greatly reduce or negate user related design changes late in the process. Crew time must be used as effectively as possible since it is limited and expensive. Early interest in SSFF design and crew interface issues help identify hardware fidelity and items that will be crucial in the crew trainer. It is the goal of this crew interface endeavor to focus SSFF on the materials research, not 'down time' involving lengthy and difficult crew activities. **Figure** 2 is a flow chart of the relationship between crew interface requirements, designers, human factors task analysis and development test plan, human factors mockup of SSFF, specific test plans and procedures, test reports, and the feedback into design.

References

NASA-STD-3000, Volume I, Revision A, October 1989, "Man-Systems Intimation Standards" This document contains crew systems integration design considerations, design requirements, and example design solutions for development of crew space systems.

SSP 50005, Revision B, August 1995, "International Space Station Flight Crew Integration Standard" This document provides Flight Crew Interface requirements applicable to the ISS extracted from NASA-STD-3000. The paragraph numbering remains consistent with NASA-STD-3000 and all references to figures and tables not contained in this document are the same figures and tables contained in NASA-STD-3000.

Cash, Martha (1996), SSFF-HER-01, "Space Station Furnace Facility Human Engineering Requirements" This is a requirements document extracted from NASA-STD-3000 and SSP 50005 and is limited to human factors requirements applicable to a furnace facility. The document is separated into three sections; Facility, Experiment Module, and Orbital Replaceable Units (ORUs).

Cash, Martha (1996), SSFF-HECTA-01, "Space Station Furnace Facility Critical Task Analysis" The critical task analysis document is a step-by-step description of furnace facility tasks with must be performed by the crew. Each step contains an explanation of how many crew are involved, which paragraph of SSFF-HER-01 applies, and whether or not tools are needed.

Cash, Martha (1996), SSFF-HETAG-01, "Space Station Furnace Facility Task Analysis-Gross." Major crew interface issues are identified and characterized.

Cash, Martha (1996), SSFF-HEDTP-01, "Space Station Furnace Facility Human Engineering Development Test Plan" This document presents tests to be performed with human subjects, program objectives, anticipated results, facility and hardware requirements, reference to CTA sections, lead time required, test dates, and required report dates.

SSP 52007-ICD-SSFF, May 13, 1996, "Space Station Furnace Facility Interface Control Document" This document specifies and controls the design interfaces between the SSFF and the ISS.

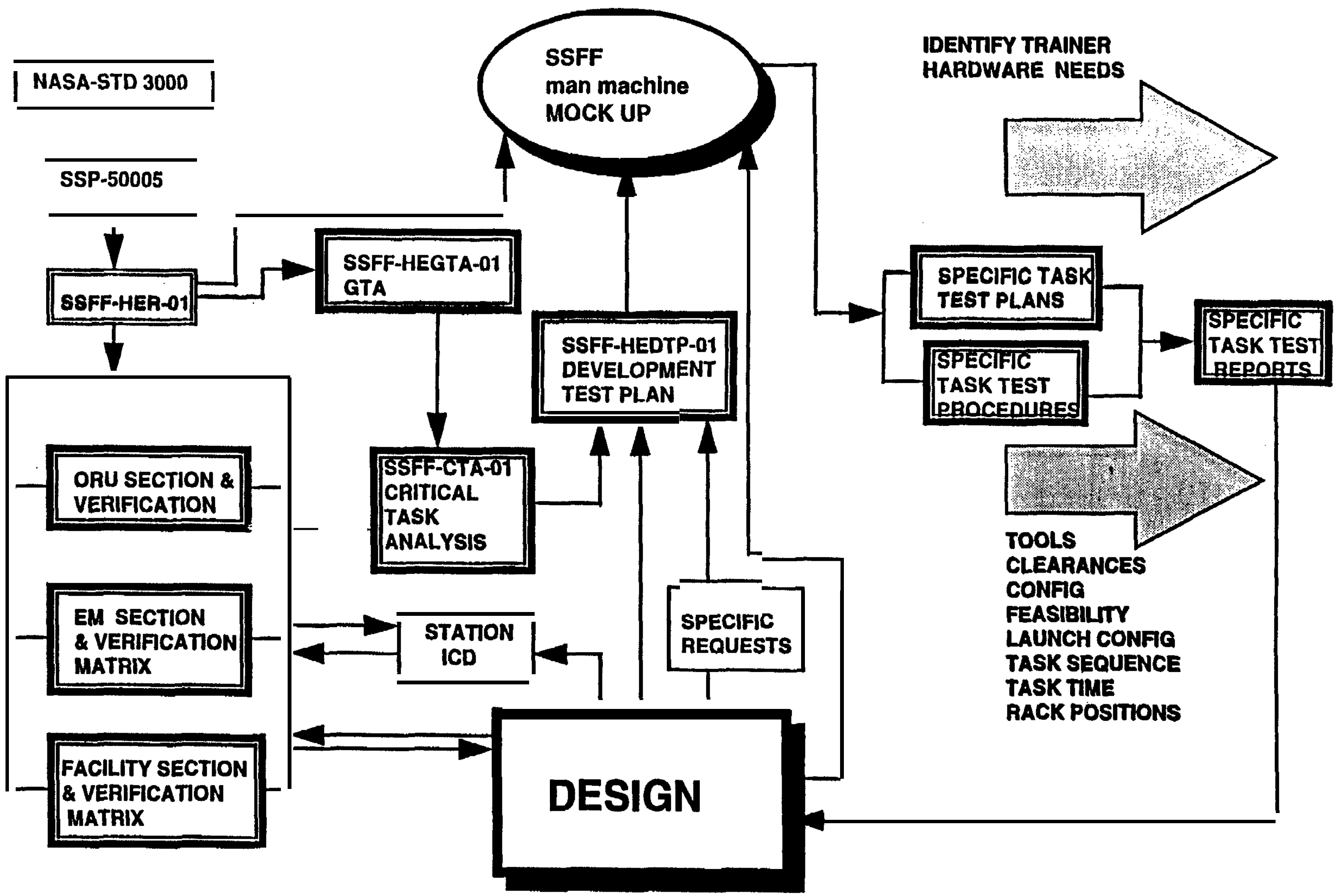

Figure 2. SSFF Man machine Interface Task Flow