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# SHUTTLE FLIGHT EXPERIMENT PRELIMINARY PROPOSAL: DEMONSTRATION OF WELDING APPLICATIONS IN SPACE

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## INTRODUCTION

In June 1991 work was initiated at MSFC on an end-effector for "Robotic Assembly of Welded Truss Structures in Space", ( 1 ). The case for welded joint assembly on orbit was discussed in the 1991 SFFP Final Report "D", ( 2 ). Data drawn from Aerobrake studies (supported by the ISAAC program) allowed the more detailed investigations that accompany a design with relatively concrete goals. This principle guides current efforts to develop scenarios that further demonstrate the utility of welding for space construction and (or) repair.

## FX MODULES

Local consensus guided the choice of representative weld joints, called FX (flight experiment) modules, that would be of general utility for space construction. These are listed in order of increasing difficulty of execution:

I. Linear Seam Butt Weld
II. Orbital Butt Weld
III. " Lap "
IV. " Elliptical Butt Weld
V. Saddle Patch Lap Welded on a Pipe
VI. Patch on a Large Diameter Pressure Vessel

For each module a scenario is hypothesized anticipating a need for that weld in an example application.

For each scenario simulations were then constructed ranging from the simple and inexpensive to higher fidelity and most expensive. A simulation considered:

A. Location, Manipulation and Guidance of --
   1. component parts to be assembled;
   2. torch that performs the joining of them.
B. Welding parameters that would optimize the joint.

Generally, the crudest simulations were prelaunch assembled parts joined on orbit by a weld torch constrained to move along a fixed path. Hard automation for on-orbit component assembly is a step toward higher fidelity. A fully robotic process represents the ultimate simulation.

## INTEGRATION

Combination of the modules into a flight experiment package is the next task. Fidelity vs. cost is again a major consideration. Reliability vs. cost becomes an added concern. In the event of a critical path failure, damage to the results would be minimized if all modules were totally independent having separate utilities, motion systems, and welding torch. Such a degree of redundance, in effect six separate flight experiments, would be expensive. At the other end of this scale, a single universal robotic end-effector capable of manipulating all component parts and performing all weld types would be ideal. It would also be expensive. End-effector complexity and its associated high developmental cost would be incurred in pursuit of reliability for the very interdependent subsystems. The best return on investment lies somewhere between these two extremes.

COMBINATIONS

Modules I. to III. are the easiest to implement.

Modules II. and III., Orbital Butt and Lap Welds respectively, represent fluid tight piping joints ( the scenario ). These are simulated by assuming one end of the pipe joint has been assembled previously into part of a pipe string. The other end is drawn from a supply and maneuvered into position using an axial approach path. Location must be maintained until welding is complete. Assuming robotic, telerobotic, or semirobotic methods would be the most useful for large future projects, a special purpose end-effector is required to accomplish the twin tasks of maintaining the relative position of the joint halves and guiding a weld torch. Welded truss structural joint studies reported last year ( 2 ) form a basis for the needed end-effector.

Module I., Linear Butt Weld, is not the simulation of a welding scenario but produces standard specimens for weld quality control studies. These specimens can be mounted on the surface of the same 4" diameter size of pipe selected for simulation of all cylindrical shaped modules ( II. thru V. ), thus it can be welded using the same end-effector as that intended for Modules II. and III.

Module IV., Orbital Elliptical Butt Weld, was inspired by the scenario: "Robotic Assembly of Welded Truss Structures In Space". In this case parts to be assembled approach each other along a path perpendicular to the strut axes which must remain parallel. This simulates placing a strut between two previously assembled nodes. The same end-effector can accomplish this task also. Modules I. thru IV. are combined.

REDUNDANCY

Module V., Saddle Patch Lap Welded on a Pipe, represents a scenario for a leak fix, mounting boss, or a tap site. Simulation involves pickup and placement of the patch for tack welding, then removal of the placement arm to finish a fluid-tight weld. The previously discussed end-effector could again be used with extensive modifications. These would be difficult to reconcile with requirements for Module IV. Modules I. to III. could be accommodated.

Two end-effectors, one specialized for Module IV. and the other for Module V. are proposed. Both could service Modules I. to III. giving a measure of redundancy while expanding the scope of the experiment. Subsystems for these end-effectors would share many design features to reduce developmental cost.

Module VI. cannot be simulated in combination with any of the other modules in such a way that a realistic scenario would be represented. Since it stands alone, development of it will be least cost effective. It will be developed later.

## ASSEMBLY

Simulation of robotic maneuvering of the end-effector relative to module components being assembled is limited to a two d.o.f. motion system configured like an "x,y plotter". All displacements take place parallel to a plane of symmetry that contains the axes of the module's components. Modules are mounted on a rotating drum that presents them sequentially to the end-effector in its plane of motion. It is there that simulated assembly and welding take place.

## DESCRIPTION

Figure 1 displays a central plan view with partial end views. Mounting tubes for Modules I. ( there are 3 of them ) and Module V. span the length of the rotating drum and give it rigidity. On the left end of the drum are mounted fixed half-tubes representing previously assembled components for Modules II. to IV. The right end simulates a "hex-close-pack" supply bundle from which unassembled parts are drawn. At the bottom is the end-effector specialized to assemble Module IV., the truss strut, shown on approach to its assembly site carrying a conjugate tube drawn from supply. The top shows the end-effector specialize for Module V., the saddle patch, with the patch positioned for tack welding.

## CONCLUSIONS

Combinations of Flight Experiment Modules that share subsystems will increase simulation fidelity at a reduced developmental cost. Additional reliability can be obtained thru partially redundant end-effectors. This approach gives the most cost effective results.

## REFERENCES


(1) Jones, C. S., Thomas, F. P., Brewer, W. V., "Robotic Assembly of Welded Structures in Space", 4th Flexible Assembly Systems Conference, ASME, Phoenix AZ, 9/13/92.

(2) Karr, G. R., et al, Research Reports, 1991 NASA/ASEE SFFP MSFC UAH UA, NASA CR-184253, 10/91.

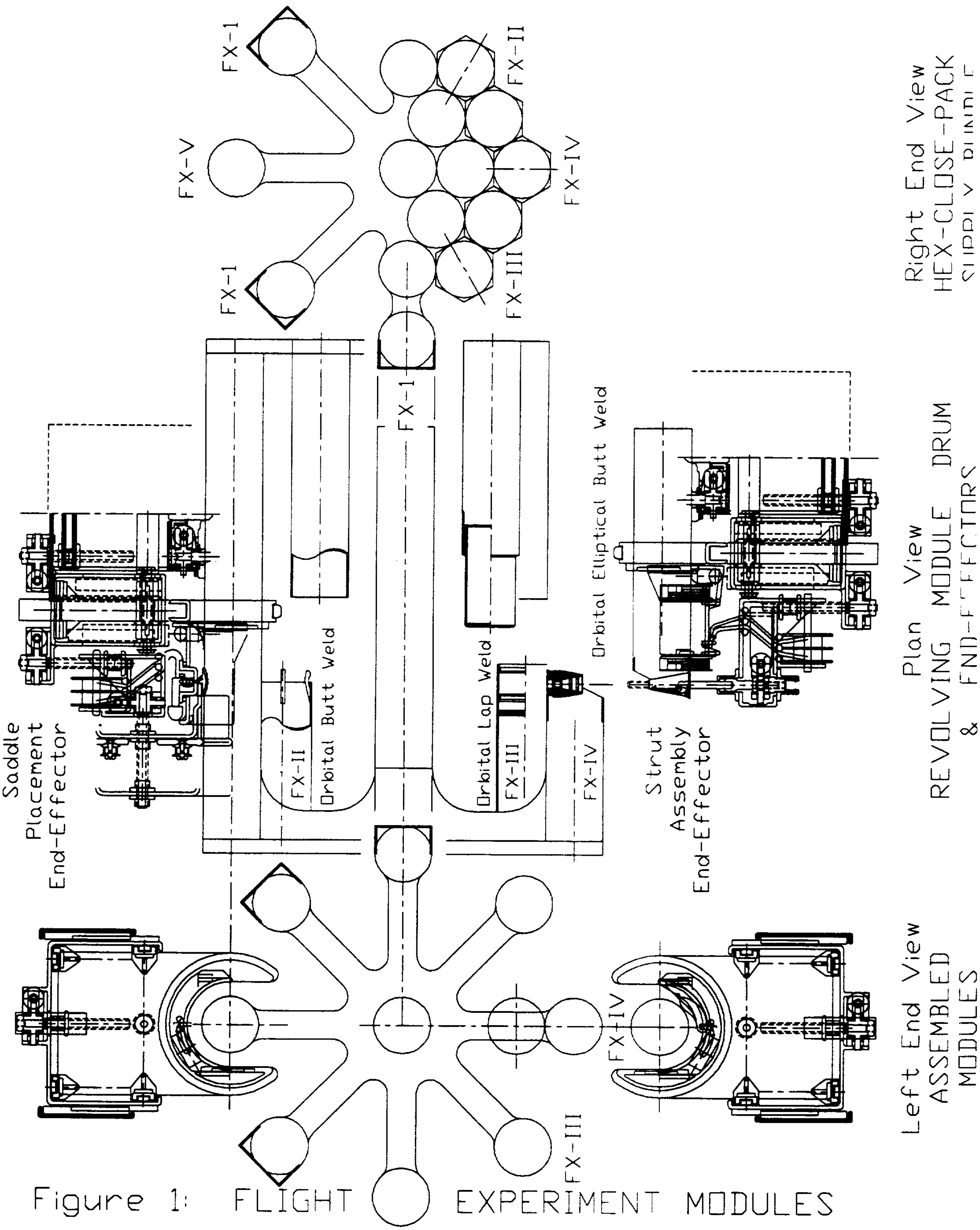


Figure 1: FLIGHT EXPERIMENT MODULES