TOOLING FOR AEROSPACE APPLICATION

Presented to the American
Ordnance Association
October 30, 1963

Edward P. Mortimer
The Boeing Company

TOOLING FOR AEROSPACE APPLICATION

I have chosen Saturn S-IC Tooling for this presentation, feeling that it is representative of the current trend towards large booster tool support. In order to go into sufficient detail I will limit the discussion to tank structures.

It might be well to start by outlining the Saturn Program Scope; that is, the responsibilities that The Boeing Company has and its interface with the National Aeronautics and Space Administration. The major activities that are contributing to the overall program are at five locations: Michoud, Marshall Space and Flight Center, Boeing - Wichita, Mississippi Test Site and Alantic Missle Range. Boeing - Wichita has responsibility for the majority of the tooling and hardware manufacture while Michoud and MSFC are responsible for assembly and testing. When the static test site at MTS becomes operative, the static testing now planned for MSFC, Huntsville, will be phased out.

The fifteen Saturn S-IC ground test and flight stages to be manufactured have a divided responsibility. MSFC will assemble and test the Fuel Test Tank, the Structural Test Stage, the Static Test Stage, the Dynamic Test Stage, and the first flight stage. Boeing will furnish some components and subassemblies to support these requirements, and in addition will have the full assembly responsibility for the Facilities Checkout Stage and second through tenth flight stages. These are all the stages defined in the current contract.

On the level of tooling and processing that I will discuss, the activity has been a joint effort between Boeing and MSFC. Acknowledgment should be given to the M-ME Division of MSFC for their part in this program, and when I speak of tools and processes, it should be mentioned that they are not necessarily Boeing conceived and developed.

Late in the last decade when it became apparent to scientists and engineers that payloads in the weight range of the three man Apollo spacecraft could not be lifted to escape velocities by existing boosters, the Saturn S-IC was conceived. As preliminary stage designs developed, it became apparent to the manufacturing engineer that radical new tooling was not forthcoming, but with few exceptions, it would be within the state of the art. Problems, inherent with the immense size, would challenge his ingenuity. Further analysis of stage design indicated that in most instances the conventional manufacturing processes would be applicable. Convention in this respect was not enough, however. As studies continued the components began to appear as suspected..... large. The meaning of this was fairly obvious; the parts could be processed conventionally, but where do you find equipment for these processes? Suitable equipment for the manufacture of the 'Y' Ring, the Cylindrical Skins, and the Gore Segments was unavailable. A similar situation existed with weld accessories. These are few of the problems we were confronted with, to which I will return later.

This presentation is limited to tank structures, however for continuity, it may be of interest to discuss briefly the overall stage construction.

The overall length from the F-1 engines to the S-II Stage Interface is approximately 140 feet. To visualize size, imagine looking at this surface from an eleventh story window. The diameter is 33 feet, excluding the four fins. It has a gross lift off weight exceeding 5,000,000 pounds, with an approximate dry weight of 290,000 pounds. The five F-1 engines produce over 7,000,000 pounds thrust.

The booster is principally of aluminum semi-monocoque construction; including engines, thrust structure, fuel tank, intertank, oxidizer tank, forward skirt, fins, engine fairings and wiring tunnels. These components are mechanically attached to one another. The tanks are fabricated of 2219 aluminum alloy; current design specifications for the remaining structure calls for 7075 aluminum alloy, with exception of the circumferential internal rings which are 7178 aluminum alloy. The cylindrical tank skins have integral longitudinal stiffeners; each tank is closed by two elliptical bulkheads. Internally, the tanks have antislosh and antivortexing baffle installations. The forward skirt assembly contains cylindrical skins stiffened externally by longitudinal hat sections and internally by circumferential rings. The intertank contains corrugated panels stiffened internally by circumferential rings. The thrust structure contains cylindrical skin panels, internal circumferential rings, forged thrust posts and shear panels, attached internally.

The oxidizer and fuel tanks are basically welded structure, similarly constructed. Tank skin assemblies from the outside surface of the stage and are closed by bulkheads, each containing 16 gore sections. The 'Y'

Ring forms the joint between the bulkhead and the skin assemblies.

The 'Y' Ring, as the name implies, has a cross-section approximating a wye. A sizable ring is made when three aluminum billets, measuring $5\frac{1}{2}$ inches thick, 27 inches high, 37 feet long, each weighing 5400 pounds are rolled to a $16\frac{1}{2}$ foot radius and joined by welding. We considered milling the billets in sections to the desired cross-section followed by welding them into a finished ring. Logistics would have been improved immensely using this process because transportation is limited to water for handling a completed 33 foot diameter ring. Welding could be accomplished at the assembly location. Feasible methods of joining were beyond the state of the art, therefore, this concept was discarded. It should be mentioned however, that MSFC has implimented a development program utilizing electron beam welding. This program has unquestionable potential in that it provides a manufacturing method for this critical part with virtually no size limitations.

To produce a 'Y' Ring turning was chosen. We were faced with finding a boring mill of proper size; if one could be found would it be adjacent to water for transportation and would it have available load time? This question was answered by locating a surplus 27 foot diameter mill and installing it at Michoud. This machine has been producing 'Y' Rings for nearly a year now. Several modifications to the mill were necessary; we installed outriggers to increase the swing, tracing equipment for contouring and machine equipment for holding purposes.

Now that we had a means of joining the skin and bulkhead our efforts were concentrated on bulkhead manufacture and particularly the gore forming.

After much thought, the options were narrowed down to four; increment forming, explosive forming, stretch forming and bulge forming. Increment forming was considered marginal from a reliability standpoint because of the difficulties in obtaining the desired contour. A development program has been implimented to form gores explosively. This program is not yet complete. A stretch form press with adequate capacity could not be found. Because of procurement lead time for a new machine, this method was eliminated. The preceding principle was not completely eliminated, however. We had been developing a method of forming material called bulge forming. The potential of this process became obvious when tests on sub-scale dies indicated that gores could be formed in a sculptured section. If full scale bulge forming proved practical, not only could we form gores, but in addition, chemical milling could be replaced with standard numerical controlled skin milling of gore stock in the flat condition.

The bulge form die consists of two halves held together with hydraulically actuated clamps. The die is of welded steel construction, faced with cast epoxy. Gore stock is held between the dies by serrated faces around the perimeter of the die halves. Hydraulic pressure is applied to the preformed blank. The water is contained by seals and capable of transmitting 33 million pounds of force. Interlocking mechanisms guard against accidental overpressurization, clamp release while the die is pressurized and seal failure.

To complete the tank primary structure it was necessary now to find a means to manufacture and assemble the cylindrical skins. Each skin requires four segments to complete the cylinder. Externally, these segments are flush, however internally, it's quite different. Not only are there integral longitudinal stiffeners spaced every (6) inches but each segment has a stepped weld land around its perimeter.

The only practical approach to machining plate stock measuring $2\frac{1}{4}$ inches by 11 feet by 26 feet was on a numerically controlled skin mill. This operation, incidentally, removes 80% of the metal before the part is complete. While the machining has caused no major problems, the forming to a $16\frac{1}{2}$ foot radius did cause some consideration. At first we considered increment forming with a brake press. Because of the irregular cross section, a filler material would be required, to be later removed. Not only did this dissuade us from this approach, but with integral stiffeners, die interference would result and the possibility of achieving a uniform radius appeared questionable.

While increment forming was being considered, the method of age forming was analyzed. Previous applications had been successful so why not use the principle for our requirements? A sub-scale development tool was made to establish feasibility and overbend requirements. After success in this development, a full size fixture was designed and built. This also successfully produced hardware.

Application of this technique was then adapted to the gore and fitting assemblies. When the various suction, loading, access, instrumentation and pressurization bosses and welded into the gore apexes, distortion occurs.

This distortion appears in the form of "out of plane flanges and oil-canning" adjacent to the fitting. To minimize the effects of this distortion on bulkhead contour a heat treat fixture was designed. Development tests showed that pressures must be applied locally to the areas of distortion. This was accomplished by a sandwich type fixture with a facility to apply the local pressure with set screws. Use of this fixture has been successful in improving contours during aging of assemblies.

Being of a mechanical nature, possibly the most intricate tooling for the structure assembly is the weld tooling. Much deliberation went into the early conceptual studies. Trade studies were made regarding fixturing, weld torch and part movement and their attitude and weld processes. Development has solved many of our problems; while some, we feel, will be encountered as we progress.

Early in the program design began on a fixture for welding the bulkhead fittings to the gore apexes. Anticipating many fittings of varying diameters we rationalized that the most versatile approach would be to construct a gantry, hang a weld head and router head from it and drive them in a circular path. Underneath would be a fixture holding the gore for routing the fitting hole, followed by welding the fitting. The fixture was placed on a dolly which runs on a track. This system would facilitate part setup, removal and increase gantry load capabilities. The fitting and gores are aligned and held to the fixture by a spider hold down arrangement, reaching from underneath the holding fixture. Because the weld torch must rotate 360°, the spider holding the gore had to be in two parts, separated by a bearing. The upper portion of the spider is driven by the same drive unit as the weld or router head. Dependent on the operation, this equipment is placed between the spokes of the spider when in use and retracted to an out-of-way position when not.

To make a gore assembly, one-eighth of a bulkhead, it is necessary to join the apex assembly to a base. The base is formed to an elliptical contour in a die similar to the apex. For dimensional control, trimming of the joining edges is required. To accomplish this operation fixtures were designed to nest and hold the parts firmly. These fixtures utilize the vacuum chucking principle. Chucking is done against inside surfaces of the parts. The fixtures nest against a gage surface on the trimming fixture which carries a motor driven router along a track. Once the joint on the apex and its mating base has been trimmed, the parts are left chucked on their respective fixtures. The two fixtures are then moved to a weld station, mated and joined by welding. An interesting feature of this station is the tilting table on which the fixtures are placed. Tilting provides a part attitude such that welding is always uphill, thus enhancing weld quality.

The coordination of this tooling family, the gantry family, the bulge form die, and subsequent bulkhead tooling is achieved by a master model. This model is of plaster construction and masters the bulkhead OML. Coordination is achieved by the use of numerous tooling holes that are transferred to the tooling families previously mentioned.

Trimming of the gore apex-base assembly is a similar operation to the previous one. The assembly is nested on a vacuum chuck where each meridian edge is trimmed with a router traveling on a track. To assure proper location of the fitting centerlines in the bulkhead assembly, the first two gores are trimmed net, however, the remaining six have their trim lines optically located in respect to the fitting centerline. Allowance is made on each part for weld shrinkage across the joint.

After trimming, the gores then are transported to the bulkhead weld station where the meridian weld is accomplished. Again a vacuum chuck is utilized as a holding device. In addition to this, the station consists of a turntable, a center post and a weld boom. The turntable and the center post serve as a support for the bulkhead, an indexing media, and provides a means for rotating the assembly to the weld position under the weld boom. The weld head travels on a track along the boom to perform the welding operation.

To close out the bulkhead assembly at its apex, a 54 inch diameter, formed dome called a "polar cap" is used. The bulkhead is moved to another position where it is trimmed to fit the polar cap. The assembly is supported in this position by a fixture at the open end and in the center where the trimming apparatus, weld head and fixturing is located. A "squirrel cage" is used to transmit hold down pressure from the center post, through the outer hold down ring, through the assembly, and into the fixture. Inside this arrangement is driven weld and router heads; each rotating through 360° while the work remains stationary.

The next operation involves joining the 'Y' Ring to complete the bulkhead assembly. This position consists of a turntable, identical to the one used at the meridian weld station, and a router and a weld head. The trimming is accomplished by plunging the router cutter through the rotating bulkhead. To prevent the bulkhead from binding as a result of weight and metal removal, spacer clamps are used. Installation of these is made while cutting progresses. Upon completion of this operation, the bulkhead is removed and the 'Y' Ring lowered onto the turntable. The bulkhead is returned to the station and mated to the 'Y' Ring using strap clamps.

To complete the basic tank assembly we need only to provide skin sections. To complete each section requires four longitudinal welds. This position consists of a holding fixture, a weld and router fixture and an alignment fixture. The skin segments are positioned on the holding fixture where the mating edges are trimmed. Alignment pressure is provided by a bar bridged by a series of vacuum cups located on both sides of the joint. When vacuum is applied, the end pressure is created by drawing the series of cups together hydraulically. The skin section is rotated from joint to joint by roller assemblies contacting the lower edge.

Assembly of the major tank components is performed in still another station called the tank assembly tower. This station contains a turntable, similar to the one previously used, a pit, an elevator, a hoist, weld equipment, and access structure. The tank assembly tower, along with the stage assembly tower, and the hydrostatic test, cleaning and calibration tower are housed in the Vertical Assembly Building now under construction at Michoud.

Our approach to tank assembly was to use the "building block" principle. That is, to stack components one on top of the other as assembly progresses. In this manner handling would be reduced. The pit provides clearance for the bulkhead during the closeout weld, permitting all welding to be accomplished at one level. This simplified the weld boom and access structure. The elevator is capable of rising internally within the tank structure, from a retracted position in the bottom of the pit, to the junction of the uppermost skin section and bulkhead; some 60 feet. It provides access for internal installations and circumferential welding of components.

Bulkhead to skin section welding is accomplished by a weld pass made simultaneously on the interior and exterior. One torch preceeds the other by approximately 8 feet on the circumference. The torches and their associated equipment are supported on the tank interior by the elevator platform and on the exterior by a mast. Welding becomes more complicated when skin sections are joined. On this joint exterior, a similar weld swquence is followed, however, on the interior we have the integral stiffeners. As previously mentioned, these members run longitudinally and are spaced approximately every 6 inches circumferentially, totaling about 200. Their cross section is the form of a 'T'. When there is access to these joints by the elevator, welding is accomplished by the equipment mounted there. Closeout welding on both tanks cannot be accomplished in this manner because the lower bulkhead blocks the passage of the elevator into the tank. To cope with this situation, a "skate" welder has been developed. This package is designed to be extremely light weight for handling. It is driven along a curved track that is clamped to the stiffener caps. The "skate" is capable of welding a series of caps and then is moved to a new position where the same process is repeated.

The last major weld to complete the tank assembly is accomplished on the LOX tunnels. These five 40 foot long, 25 inch diameter tubes run from the upper fuel bulkhead through the tank to the lower bulkhead. The tunnels surround the LOX ducts as they pass from the oxidizer tank aft through the fuel tank to the engines. It may be of interest to diverge here to talk of the tunnel construction. Presently, tunnels are being developed at a sub-contractor using the shear forming process. A forged billet of aluminum is formed to a 40 foot length, with a wall thickness of 108 thousandths. The tunnel is mechanically attached to the upper bulkhead through a bellows arrangement. It is directly attached to the lower bulkhead by a weld. This joint has limited accessibility. The path the torch generates is oval shaped and the weld attitude is not conventional because of the joint plane angle. In spite of the joint uniqueness, a piece of equipment has been proposed by a sub-contractor that promises to accomplish this task.

Perhaps the most critcal area not yet discussed is radiographic inspection of the weld joints. With a calculation of 33,000 inches of welding, it was apparent that the conventional X-ray techniques would be too time consuming for economical processing. A better method had to be found. The idea of mechanized X-ray was suggested and a feasibility study was initiated. The study resulted in a conclusion that a system was feasible and design got underway.

The mechanical X-ray system developed is basically an X-ray source, well shielded with a bellows. A film reel unit is aligned with the X-ray source on the opposite side of the part. Dependent on the particular assembly, the source - reel unit either travels along the work as inspection progresses, or the work moves and the source - reel unit remains stationary.

The reel unit functions on the same principle as a camera; a shot is taken and the exposed film is wound onto a reel moving the unexposed film into position. This process continues until the entire weld has been inspected.

Possibly the most unique development in this system is the bellows. They are made of lead impregnated neoprene and must fit part contour to limit radiation to a level where normal work activity is not affected.

I feel the welding process should be discussed in closing this presentation. It might be of interest to know why we chose the process we did and what particular problems we have encountered.

TIG mechanized welding was chosen for two reasons:

(1) Experience in welding 2219 aluminum.

(2) It was felt that TIG welding would provide better weld bead control over the various weld attitudes encountered.

To provide versatility, equipment has been ordered with both TIG & MIG capabilities.

Weld backups, where they are used, align the parts but do not cast the underbead. The clearance in the back-up beneath the weld joint carries the purge gas.

The weld schedules call for three passes:

(1) A shallow tacking pass without any wire feed.

(2) A penetrating pass without wire feed forming the underbead.

(3) The final filler pass with wire feed.

Edge preparation varies. A straight butt joint is used on·

(1) Skin section to skin section welds.

(2) Fitting to gore welds.

(3) Polar cap to bulkhead weld.

(4) 'Y' ring to bulkhead weld.

A double 'V' groove is used on the 'Y' ring to skin weld. On the gore apex to base weld an interlocking convex joint is used.

Difficulties have been experienced with fixtures adjacent to the weld. This was particularly true welding the fitting to the gore and the polar cap to the bulkhead. The steel spider and backups became magnetized causing arc blow. The modification to non-magnetic stainless steel and aluminum has eliminated this problem.

Generally speaking, welding of 2219 aluminum has been very successful on the Saturn S-IC Program. Repairs have been few. This is gratifying when one thinks of 33,000 inches of weld for each stage manufactured.