II. Session 2: Space Shuttle Propulsion Materials, Manufacturing, and Operational Challenges

A. External Tank (ET) Materials, Manufacturing, and Operational Challenges – K. Welzyn

The External Tank forms the structural backbone of the Space Shuttle in the launch configuration. Because the tank flies to orbital velocity with the Space Shuttle Orbiter, minimization of weight is mandatory, to maximize payload performance. Choice of lightweight materials both structural and thermal was necessary. The tank is large, and unique manufacturing facilities, tooling, and handling, and transportation operations were developed. Weld processes and tooling evolved with the design as it matured through several block changes, to reduce weight. Non Destructive Evaluation methods were used to assure integrity of welds and thermal protection system materials. The aluminum-lithium alloy was used near the end of the program and weld processes and weld repair techniques had to be refined. Development and implementation of friction stir welding was a substantial technology development incorporated during the Program. Automated thermal protection system application processes were developed for the majority of the tank surface. Material obsolescence was an issue throughout the 40 year program. The final configuration and tank weight enabled international space station assembly in a high inclination orbit allowing international cooperation with the Russian Federal Space Agency. Numerous process controls were implemented to assure product quality, and innovative proof testing was accomplished prior to delivery. Transportation and handling procedures for such a large structure were unique. The manufacturing and material processing issues will be discussed in depth in the paper.

B. Space Shuttle Main Engine (SSME) Materials, Manufacturing, and Operational Challenges – K. Van Hooser

A number of materials and manufacturing challenges were encountered within the Space Shuttle Main Engine. Manufacturing of the major components including the nozzle, main chamber, combustion devices, turbo-machinery, the power-head, instrumentation, and valves and actuators provided unique challenges. Significant development was required for the final configuration of the high pressure pumps. Unique materials were utilized for single crystal cast turbine blades and ceramic rolling element bearings. Fracture control was implemented to assess life limits of critical materials and components. Survival in the hydrogen environment required assessment of hydrogen embrittlement. Development of a new high strength alloy was accomplished for the hot gas wall of the Main Combustion Chamber (MCC). Instrumentation systems were a challenge due to the harsh thermal and dynamic environments within the engine. Extensive inspection procedures were developed to assess the engine components between flights. In the production phase of the program extensive changes were made to the chemical processes used for hardware to eliminate ozone depleting solvents and the carcinogens. Unique handling equipment was needed for integration in the Orbiter. These material and manufacturing challenges will be discussed within the paper.

C. Reusable Solid Rocket Motor (RSRM) Materials, Manufacturing, and Operational Challenges – D. Moore

The Reusable Solid Rocket Motor represents the largest solid rocket motor ever flown and the only human rated solid motor. The motor evolved during the life of the program and developed substantial understanding of environments and material response to environments. Because of the multi-decade program duration material obsolescence was addressed, and requalification of materials and vendors was sometimes needed. Thermal protection systems and ablatives were used to protect the motor cases and nozzle structures. Significant understanding of design and manufacturing features of the ablatives was developed during the program resulting in optimization of design features and processing parameters. Unique and innovative sealing system designs evolved and material formulations were developed to meet requirements at low temperature. Advanced thermal barrier materials were incorporated in a number of nozzle joints. The project advanced technology in eliminating ozone-depleting materials in manufacturing processes and the development of an asbestos-free case insulation. Manufacturing processes for the large motor components were unique and safety in the manufacturing environment was a special concern. Post flight inspection procedures were developed to assess performance in the flight environments. Transportation and handling approaches were also needed for the large hardware segments. The manufacturing, material processing, and operational issues will be discussed in depth in the paper.

D. Solid Rocket Booster (SRB) Materials, Manufacturing, and Operational Challenges – D. Wood

The solid rocket booster element integrates the solid rocket motor with the booster subsystems including ignition, thrust vector control, avionics and instrumentation, range safety, recovery, separation and pyrotechnic systems, the thermal protection system, and provides structural interface with and release from the launch pad. The solid rocket boosters are designed for recovery, refurbishment, and reuse. This represented the only time a solid rocket booster system was reused. The three main parachutes that lower the SRBs to the ocean are the largest parachutes ever designed and the SRBs are the largest structures ever to be lowered by parachutes. Booster recovery from the ocean is a unique process; it had never been done before. Recovery operations was a unique and significant operational challenge, requiring personnel, facilities, and recovery, transportation, and ground support equipment Hardware attrition occasionally occurred due to water impact. Assembly and integration of the booster subsystems was a unique process and acceptance testing of reused hardware components was required for each build. Materials and subsystems evolved over the life of the program including the thermal protection system materials and application processes, structural subsystems, and parachute systems. Transportation, handling, and assembly operations were unique as were disassembly following recovery and refurbishment for reuse. These challenges will be discussed in depth in the paper.