CRAWLER TRANSPORTER NOISE CONTROL STUDY AND NOISE CONTROL DESIGN

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1. INTRODUCTION

The Crawler Transporter is the world's largest tracked vehicle known weighing 2,721 metric tonnes with a length of approximately 40 metres and a width of approximately 35 metres. The Kennedy Space Center has two Crawler Transporters that were built by the Marion Power Shovel Company in the 1960's for the Apollo/Saturn V Program. The Crawler Transporters have been maintained and retrofitted for use in the Shuttle Vehicle Program. The overall Crawler Transporter design and propulsion systems are relatively unchanged from the Apollo/Saturn V program to the present.

The Crawler Transporter is electrically driven by 16 traction motors. The power is provided by four on board diesel gensets. Two 2750 horsepower Alco engines power DC generators and two 1065 horsepower White Superior engines power AC generators. In addition to supplying the needs of the traction motors the on board generated power also supports the needs of the hydraulic leveling and jacking system, steering system, lighting and ventilation systems. The Crawler Transporters are constructed with redundancy built into the design of all major operating systems.

The work force on board the Crawler Transporter during a rollout is approximately 18 engineers, technicians and support personnel. The United Space Alliance (USA), owned by Lockheed Martin and Boeing, is the prime contractor for NASA's space shuttle program. USA retained Noise Solutions Inc. (NSI), a company out of Calgary that provides turn-key noise control solutions with guaranteed results. NSI commissioned Faszer Farquharson to evaluate and develop conceptual noise control measures for NASA's two crawler transporters in order to reduce the noise level exposure of the crawler work force.

2. CRAWLER NOISE SOURCES

The Crawler Transporter is powered by four onboard engine powered electric generators. Two 2750 horsepower Alco engines supply the DC power requirements and two 1065 horsepower White Superior engines supply the AC power requirements. The engines are all housed in a single room within the superstructure of the Crawler Transporter designated as the Crawler Engine and Equipment House. The engines are situated at 90 degrees to the travel of the Crawler Transporter with the Alco engines on the outboard ends and the White Superior engines located on either side of the center of the Crawler Transporter superstructure. The engine and generator sets are mounted on vibration isolators to the floor of the Crawler Transporter Engine and Equipment House. Combustion air for the engines is drawn from the interior of the Crawler Transporter Engine and Equipment House. The engines all exhaust to the underside of the Crawler Transporter superstructure with an exhaust outlet found near each of the four corners of the unit. Large radiators for each of the four engines are situated outside the Crawler Transporter Engine and Equipment House at the travel or drive ends of the Crawler Transporter.

The hydraulic pump systems are housed in the center of the Crawler Transporter Engine and Equipment House opposite the control room. The jacking and leveling hydraulic system (JEL) is located on the opposite side of the Crawler Transporter from the control room. From this location hydraulic fluid under high pressure is directed to the jacking and leveling systems located at the four corners of the Crawler Transporter. The high pressure hydraulic lines take a variety of paths starting inside the Crawler Engine and Equipment House exiting to the underside of the superstructure then turn up the outside of the superstructure to the jacking and leveling system at each corner. The JEL system pumps are skid mounted and sit directly on the floor of the Crawler Transporter Engine and Equipment House. The high pressure JEL lines are rigidly connected to the floor of the house and to the superstructure of the Crawler Transporter. The JEL system return lines follow a similar path back to the large hydraulic fluid reservoir located centrally in the Crawler Transporter Engine and Equipment House.

The steering hydraulic system is similar in design to the JEL system. The steering system pumps are located between the control room and JEL system pumps. This system is also skid mounted directly to the floor of the Crawler Transporter Engine and Equipment House. The supply lines are again rigidly mounted to the superstructure of the Crawler Transporter.

The super charger system supplies hydraulic fluid from the reservoir to the intake of the JEL system and steering system pumps. The supercharger pumps are skid mounted to the floor of the Crawler Transporter Engine and Equipment House. Supply lines leading to the JEL and steering hydraulic pumps are rigidly mounted to the floor and or the skids of the pump systems.

The ventilation for the Crawler Transporter Engine and Equipment House is supplied by a number of 36" and 40" inch diameter fans located along the sides of the Crawler Transporter Engine and Equipment House. The ventilation fans are generally located at positions where the cooling air from the fans will sweep the engine and generator casing areas and the hydraulic pump areas. The cooling air is to exit through grated openings in the floor of the Crawler Transporter Engine and Equipment House. The ventilation fan system is supplemented by a number of portable propeller fans that were moved as required to provide additional air movement inside the Crawler Transporter Engine and Equipment House. The four man doors leading into the Crawler Transporter Engine and Equipment House were open for ventilation purposes during the rollout.

Noise sources associated with the four trucks include the movement of the trucks, the operation of the jacking and leveling system at each leg, the steering system, the truck propulsion motors, mechanical noise associated with the movement of the shoes over the boogies and sound of the crawler way gravel being crushed.

3. CRAWLER OPERATIONS

The rollout operation for a fully loaded crawler requires the services of approximately 18 engineers, technicians and support personnel. The operators are divided between stationary positions and roaming positions. Stationary positions include personnel in the control room, the active steering cab and in the Crawler Transporter Engine and Equipment House overseeing the operation of the engines and hydraulic systems. Roaming positions include each of the four trucks, the underside of the superstructure and the catwalk around the exterior of the Crawler Transporter Engine and Equipment House. Personnel stationed inside the Crawler Transporter Engine and Equipment House are generally the individuals subject to higher than desired sound levels. The personnel located in the control room and the steering cabs are generally more concerned with reduced noise levels for better communication purposes. Communication between Crawler Transporter personnel is facilitated by the use of radio headsets for all personnel outside the control room.

A rollout operation takes from 14 to 16 hours depending on how many stops occur along the 3 mile trip from the Vehicle Assembly Building to the launch pad. Stops for any reason are diagnosed istantly and any repairs required are undertaken immediately by the crawler operating crew.

4. MEASUREMENTS AND DATA ANALYSIS

A requirement of USA was to undertake measurements of a fully loaded working crawler during a rollout without interfering with its operation and design the noise control to reduce the sound levels under the fully loaded conditions. In order to obtain the required detailed sound level data required to design and engineer noise control measures, a combination of sound pressure level measurements and sound intensity measurements were undertaken.

The sound pressure level measurements were conducted with a Brüel & Kjær Model 2260 Precision Real Time Sound Analyzer and a Brüel & Kjær Model 4189 Microphone. The sound intensity level measurements were conducted with two Brüel & Kjær Model 2260 Precision Real Time Sound Analyzers each equipped with a Brüel & Kjær Model 4197 Microphone Pair mounted on a 2683 Sound Intensity Probe. These systems were used to measure and record 1/3 octave band frequency sound intensity and sound pressure level spectra.

Sound pressure level measurements were undertaken of noise sources that did not vary with a fully loaded crawler and that could be isolated by turning equipment on and off. The sound intensity measurements were taken of equipment that produced maximum sound level when the crawler was fully loaded and that could not be isolated from other operating equipment.

The sound pressure level measurements were presented as 1/3 octave sound pressure level graphs and the sound intensity measurements were presented as 2D contours mapped onto an outline of the measured equipment and 3D sound intensity contours providing and indication of sound energy flow. This information was used to evaluate the significant noise sources, determine conceptual noise control measures and predict potential noise reductions for the various systems.

5. NOISE CONTROL MEASURES

The conceptual noise control systems that were presented included an acoustically enclosed walkway and vestibule system that would compartmentalize the crawler engine house, ventilation and radiator fan noise control, JEL hydraulic system noise control including isolation of hydraulic lines, equipment skids and in-line hydraulic silencers, upgraded engine exhaust mufflers, upgrading of the control room/engine room demising wall and engine house acoustical treatment.

The conceptual noise control measures were presented to USA and NASA staff for review and it was decided to proceed to an engineered noise control design stage for all of the conceptual noise control measures with the exception of the radiator fans and the compartmentalization of the engine house.

Upon completion of the engineered noise design stage orders were placed for upgraded mufflers and silenced ventilation fans for one of the crawler transporters. The upgraded mufflers have been fabricated and shipped to the Kennedy Space Centre and are ready for installation.