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Space shuttle crawler transporter hydraulic system sound control measures

Clifford C. Faszer[a]
Faszer Farquharson & Associates Ltd.
#304, 605 - 1st Street SW
Calgary, Alberta, T2P 3S9
Canada

Rod MacDonald[b]
Noise Solutions Inc.
#301, 206 – 7 Avenue SW.
Calgary, Alberta T2P 0W7
Canada

ABSTRACT

The United Space Alliance (USA) sought outside assistance to evaluate and develop noise control measures for NASA's two crawler transporters located at the Kennedy Space Centre. Real time sound intensity measurements and sound pressure level measurements of a fully loaded crawler were taken with handheld measurement systems. The sound levels were analyzed and sound intensity mapping techniques used to determine the major noise sources on the crawler and the sound level contributions of the various noise sources. Conceptual noise control measures were then determined and presented. Based on the conceptual ideas detailed noise control measures were engineered based on achievable noise reduction targets. Upgraded engine exhaust silencers and ventilation fans and silencers have been installed on both crawler transporters as the first phase of the noise control measures. A prototype inline hydraulic silencer for the jacking and leveling hydraulic system was designed and tested. The results of the prototype testing indicated that a significant reduction of the hydraulic system noise could be achieved. Hydraulic silencers based on the prototype design have been manufactured and are now installed on one of the crawler transporters along with resilient hydraulic line and hydraulic pump mounts as the second phase of noise control measures. Sound level measurements taken at similar locations and operating conditions on both crawler transporters indicate that a significant amount of noise reduction has been achieved with the installation of the hydraulic system noise control measures.

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 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 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. Figure 1 presents an overall layout of the major equipment in the Crawler Transporters.

[a] Email address: ffa@telusplanet.net
[b] Email address: rmacdonald@noisesolutions.com

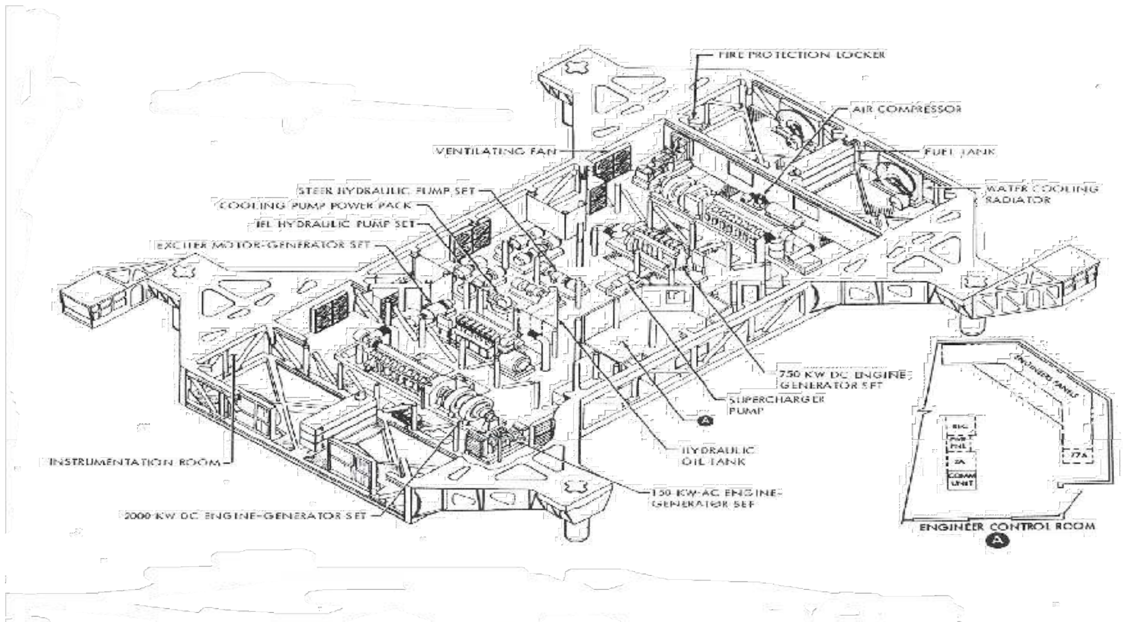

Figure 1: Overall layout of major equipment in the Crawler Transporters

The work force on board the Crawler Transporter during a rollout is approximately 18 engineers, technicians and support personnel.

This paper briefly outlines the results of the 2nd phase of an on-going sound attenuation program.

2 SOUND ATTENUATION METHODOLOGY

2.1 Overview

The approach involved undertaking sound pressure level and sound intensity level measurements of the significant noise sources on the Crawler Transporter(CT) during a shuttle roll out when it is fully loaded. Sound intensity measurements were used to assist in determining the significance of noise sources located in a multi-source noise environment. A preliminary assessment of CT noise sources and as-built issues such as the engine and generator sets exhausting to the underside of CT's superstructure; the engines radiators drawing cooling air inwards towards the CT housing; the JEL system pumps, steering hydraulic system and super charger pumps that are rigidly mounted to the CT superstructure with their hydraulic lines crisscrossing under the CT and inducing noise into all areas of the CT, including the Control Room and the Cabs; the ventilation cooling air exiting through louvered openings in the floor of the Crawler Transporter Engine and Equipment House; and lastly, the noise sources surrounding the movement of the trucks particularly the jacking and leveling system, the steering system, the truck propulsion motors, mechanical noise associated with the movement of the shoes over the bogies and sound of the crawler way gravel being crushed. Sound pressure level measurements were made of the existing noise sources that could be readily identified and isolated from other sources. Many of these sound pressure level measurements were completed in year 2000, with the Crawler Transporter connected to shore power to assist in the isolation process.

Based on the initial survey, a total of nine (9) separate noise mitigation recommendations were targeted for an overall reduction in the Control Room noise level to 85 dBA or below, lowering the overall Engine/Pump room noise level by 5 dBA or better and reducing the overall noise level in the general area under and around the CT by 8 to 10 dBA. These recommendations include the installation of an acoustical isolation wall between the Control Room and the Engine/Pump Room, the installation of acoustical vestibules and doors at the four Engine/Pump Room's door openings, the installation of absorption panels on the Engine/Pump Room's ceiling and walls, isolating the JEL skid and piping from the CT's superstructure, providing in-line hydraulic silencers for the JEL hydraulic piping systems, the installation of inlet acoustical fan forced ventilation hoods under the CT's floor on the existing louvered floor openings, replacing wall inlet vent fans with acoustical fan forced exhaust ventilation hoods, and lastly replacing and isolating the engine muffler and exhaust systems from the CT's superstructure. The implementation of these noise control measures has been phased. Phase 1 has been installed on both CT1 and CT2 and includes the upgraded engine exhaust mufflers and upgraded and silenced ventilation systems. The acoustical performance of the Phase 1 measures was presented in an earlier paper at Inter-Noise 2004 [1]. Phase 2 has been installed on CT2 and includes the hydraulic system noise control recommendations and the acoustical performance of these measures is presented in this paper.

2.2 Instrumentation

Sound level measurements were undertaken of the Crawler Transporters during a site visit on May 12 - 13 with the CTs stationary. Sound intensity and additional sound pressure level measurements were undertaken on August 12 - 14, 2000 during a shuttle roll-out. 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. This system measures and records 1/3-octave band frequency sound pressure level spectra. The measurement system was field calibrated at the start of each series of measurements and checked upon completion using a Brüel & Kjær Model 4231 Sound Pressure Level Calibrator. 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 level spectra. The measurement systems were field calibrated at the start of each series of measurements and checked upon completion using a Brüel & Kjær Model 3541 Sound Intensity Calibrator and Model 4228 Piston Phone. Subsequent sound pressure level measurements of the noise reductions achieved from the implementation of the phase 1 and 2 noise control measures have been undertaken with a Brüel & Kjær Model 2260 Precision Real Time Sound Analyzer and a Brüel & Kjær Model 2250 Hand Held Analyzer. Audio recordings of some measurements have also been undertaken with a Brüel & Kjær Model 2236 Sound Level Meter and a Sony TCD-D8 DAT Recorder and with the audio recording feature in the Brüel & Kjær Model 2250 Hand Held Analyzer.

2.3 Measurements

Sound Pressure Level (SPL) measurements were taken of the ventilation fans and radiator fans and in various locations in and around the crawler transporter with and without noise control measures installed. Sound Intensity measurements were taken throughout the inside and around the CT periphery of the major noise sources that change intensity level with load including the ALCO/WHITE engines, Hydraulic Supercharger Pumps, Steering Pumps, JEL Pumps, Control Room Floor and Walls, Cab 1 Side/Rear Walls, Truck front/outside faces, and JEL cylinder corners.

The sound intensity level measurements consisted of a series of measurements taken on a known grid relative to the noise source or surface under consideration. A 0.5-meter measurement grid was used for all sound intensity level measurements with the exception of the trucks, in which case a

0.75-meter measurement grid was used. Sound pressure level measurements are also automatically recorded along with the sound intensity measurements.

2.4 Processed Data – Sound Pressure Level (SPL)

The sound pressure level measurements provide an overall sound level of all the combined noise sources at the microphone position. Thus, sound pressure levels are very useful when it is possible to measure one piece of equipment at a time. When undertaking interior sound level measurements the sound pressure level includes the direct sound radiating off of a sound emitting surface, reflected sound from first and second reflections off of various surfaces, and the reverberant component from sound that has reflected many times from the various interior surfaces present. Sound pressure level measurements are not as useful for discerning the amount of sound caused by an individual sound source in a multi-source environment.

Sound pressure level measurements have been useful to determine the noise reduction achieved from various noise control measures by undertaking measurements at a similar location and under similar operating conditions on the treated crawler and the un-treated crawler.

The measured 1/3 octave band sound levels are presented as bar graphs in the Reduced Data in the CT Sound Attenuation Study and Installation document [2].

2.5 Processed Data – Sound Intensity Level (SIL)

The sound intensity measurements provide an indication of both the sound intensity level and the direction of the sound energy flow. Thus, a sound intensity measurement indicates that sound may be flowing out of or into a surface. In order to visualize the sound energy flow, the sound intensity data was entered into mapping software to generate 1/3 octave band sound intensity noise contours of the major noise sources and surfaces. The contours are presented as 2D maps with an outline of the equipment overlaid onto the contour and a 3D contour map to provide a graphic representation of sound energy flow from the surface of interest. The sound level is represented by different colors for both the 2D and 3D maps. The sound intensity contours are presented in the reduced data sound contours appendix and an example of the raw sound intensity data is presented in a tabular form in the CT Sound Attenuation Study and Installation document released in 2000 [2]. An example of a sound intensity plot is presented in Figure 1.

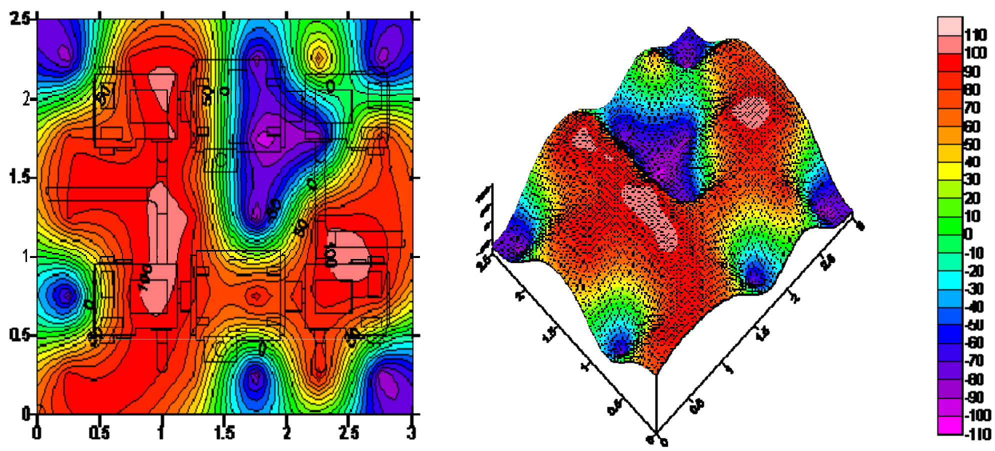

Figure 1: JEL hydraulic pumps 400 Hz Sound Intensity Plot

3 STUDY RESULTS AND NOISE REDUCTIONS ACHIEVED

3.1 Phase 1 Noise Control Measures

The Phase 1 noise control measures consisted of removing the old and installing new upgraded engine exhaust mufflers and upgrading and silencing the engine/pump room ventilation. The first phase was designed to reduce noise levels around the CT both on the ground and on the walkways. A secondary benefit of the above upgrades resulted in improved air quality in the engine/pump room. A detailed description of the phase 1 noise control measures was presented in a previous inter-noise 2004 paper [1] and is not repeated here. These upgrades have been completed on both CT1 and CT2

3.2 Phase 2 Noise Control Measures

The phase 2 noise control measures consisted of the following changes to the Jacking Elevating and Leveling (JEL) hydraulic system. See Figure 2.

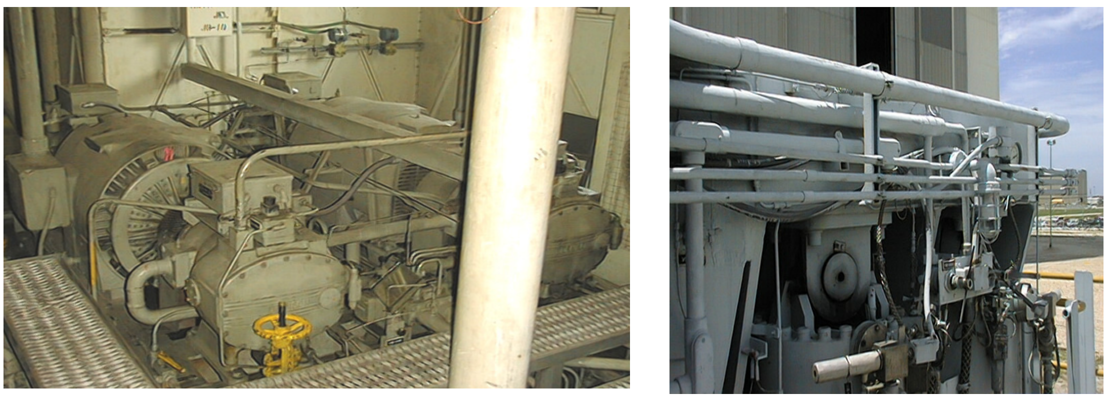

Figure 2: JEL hydraulic pumps JEL hydraulic jack

- Removal of the solid steel shim plates under the JEL skids at the restraining bolt locations and replacing them with restrained rubber isolators, see Figure 3.
- Replacing all of the original rigid hydraulic pipe clamps with a resilient clamp that incorporates an elastomeric element into the body of the mount, see Figure 4.
- Replacing some sections of rigid hydraulic piping with flexible lines, see Figure 5.
- Installing two styles of inline hydraulic silencers in each of the 4 hydraulic pipe runs for each corner of the CT, see Figure 6. A nitrogen charged bladder silencer and a two chamber tuned reactive silencer were used.

Figure 3: CT1 solid metal shim CT2 resilient mount

Figure 4: CT1 rigid metal clamps CT2 resilient pipe mounts

Figure 5: flexible hydraulic hose

Figure 6: CT1 no inline hydraulic silencers CT2 inline hydraulic silencers

3.3 Remaining Noise Control Measures

The remaining noise control measures that will be implemented in future phases include implementing sound lock vestibules at the engine/pump room's doors, adding acoustical absorption on the walls and ceilings of the engine/pump room, and the application of an upgraded sound reduction wall between the engine/pump room and the control room. These measures will reduce the noise levels in the control room, and further lower noise levels outside of the CT because of a decrease in the reverberant sound level inside the engine/pump room.

4 MEASURED NOISE REDUCTION

Sound pressure level measurements were taken at 14 similar locations in and around both CT1 and CT2. Both CT1 and CT2 were operating with the JEL hydraulic system set to 3000 psi to simulate a loaded condition. The results of the sound pressure level measurements and the noise reduction achieved are presented in Table 1.

Table 1: Measured Sound Pressure Levels and Noise Reduction Results

Measurement Location	Measured Sound Pressure Levels (dBA)		Noise Reduction Achieved (dBA)
	CT1 Original JEL Hydraulic System	CT2 JEL Hydraulic System with Noise Control Measures Installed	
Control room position 1 centre	85.6	76.3	9.3
Control room position 2 by MCC	86.4	78.2	8.3
Pump room over supercharger	102.5	99.7	2.8
Pump room over JELs	109.4	106.3	3.1
Side 2 catwalk beside AC duct	90.0	75.9	14.1
CAB 1 AC on	70.6	57.3	13.3
Side 4 catwalk beside JELs	91.3	82.3	9.0
CAB 3 AC off	69.4	54.1	15.3
On ground below crawler under the JEL area	96.4	87.9	8.4
On ground below crawler under the control room	94.3	83.6	10.7
On ground side 4	86.9	80.0	6.9
On ground end 1	80.0	71.0	9.0
On ground side 2	87.1	75.3	11.8
On ground end 3 E4 radiator fan on	85.2	80.8	4.4

It can be seen from Table 1 that the installation of the hydraulic system noise control measures has achieved some significant noise reductions in a number of areas.

- The control room sound levels were reduced by 8 to 9 dBA from 86 dBA to the 76 to 78 dBA range. Upgrading the control room/engine pump room wall will provide further noise reductions.
- The sound level in the engine pump room was reduced by 3 dBA, a good reduction as acoustical room treatment has yet to be installed.
- Noise level reductions on the catwalk ranged from 9 to 14 dBA and reductions of 4 to 11 dBA were achieved around and under the crawler transporter.
- The greatest level of noise reduction, 13 to 15 dBA was achieved in the CABs.

The above measured noise reductions do not fully represent the reductions that would be present with all of the crawler transporter noise sources operating however they can be compared to the noise reduction targets for an early indication of potential noise reductions that may be achieved. The targets are an overall reduction in the Control Room noise level to 85 dBA or below, lowering the overall Engine/Pump room noise level by 5 dBA or better and reducing the overall noise level in the general area under and around the CT by 8 to 10 dBA.

5 SUMMARY

In summary based on the measured noise level difference between CT1, with an untreated JEL hydraulic system, and CT2 with a treated JEL hydraulic system, the hydraulic system noise control measures have provided significant noise reductions to the overall sound level in and around the crawler.

6 ACKNOWLEDGEMENTS

The article is dedicated to the entire CT design, operations and maintenance crew, for displaying unparallel pride in the two Crawler Transporters and displaying a pro-active stance to support the myriad of changes that are resulting in a quieter operational environment during crawler transporter operations.

7 REFERENCES

[1] C. Faszer, R. Margasahayam and R. MacDonald, "Space Shuttle Crawler Transporter Sound Attenuation Study" *Proceedings of INTER-NOISE 2004,* paper in04_545, 2004.

[2] Crawler Transporter Sound Attenuation Study and Installation, NSI documentation, Phase II Report, (2000).