ONR Contractor Report A0002
Final Report

Complete the Test Program of the American Underpressure System (AUPS)

Volume I – Final Report

Mo Husain, Robert E. Apple,
John Angles, Henrry M. Hunter,
Charles F. Quirmbach and Dmitry Altshuller

MH Systems, Inc.
San Diego, CA

Prepared for

Office of Naval Research
U.S. Department of Defense
800 North Quincy Street
Arlington, VA 22217

under Contract No. N000-14-02-C-0515

March 2004

MH Systems, Inc.
Naval Architects and Analysts
10951 Sorrento Valley Road, Suite 2F
San Diego, CA 92121

Executive Summary

The U.S. Congressional Oil Pollution Act of 1990 allowed for the evaluation and approval of alternatives that can be determined to have equal or better performance than the double hull in protecting the marine environment. The Act also specified studies on spill prevention for existing tankers and specifically mentioned research and development on the use of vacuum in tanks.

The American Underpressure system (AUPS), an active inert gas controlled system utilizing vacuum technique drastically reduces or totally prevents spillage from accidental rupture of the hull. The AUPS has been tested in full scale on USNS Shoshone under the aegis of the Office of Naval Research (ONR) and completed in 2002. This report is prepared to complete the analysis of that test, titled - "Complete the Test Program of the American Underpressure System (AUPS)", also under a contract from ONR.

The tasks set forth in the Statement of Work have been completed, and the results of the design and analysis efforts are sufficiently conclusive to justify and support rulemaking by the United States Coast Guard. The USCG in 1998 provided comprehensive guidance on the technical and analytical information that would be needed for rulemaking changes. The complete detailed responses to this guidance are included in this report as Appendix B and are being sent separately to the USCG.

The status and conclusions of specific task areas are summarized in the following paragraphs:

Control Systems: Performance Requirements for the control system have been defined. Control is exercised over both pressure and gas composition in the ullage space. The overall control system design, the hardware proposed for use and the system architecture are adequate to meet the requirements. The human interface, including controls and displays, manning, and provision for emergency and long-term maintenance has been defined.

A mathematical model and a real-time simulation program have been developed. Runs have been made to examine casualty modes of operation. Groundwork has been laid for further simulation at the detail design stage using selected actual hardware and software. Special attention has been given to the evaluation of transient system behavior and stability.

The system is fully automatic. There is no initiation of the system after the casualty occurs; the system is continually active from the time cargo is loaded until it is discharged. There is no requirement for human intervention. The system can respond to the sudden imposition of pressure disturbances as would occur in tidal and current force variations.

Generic System Design: Designs have been prepared for AUPS installations on typical tankers. An in-depth design was conducted on a 70,000 dwt tanker. Also, the system received an extensive design review for 188,000 and a 300,000 dwt tankers. Drawings and specifications in specific areas of fire safety, vapor generation and safety, machinery and piping, and electrical systems are sufficient to support USCG review and rulemaking.

Extensive analysis includes: Performance Effectiveness – Outflow Analysis, Risk Based Design Analysis, Structural Analysis, and Economic Feasibility.

Outflow Analysis: The outflow analysis conformed with the rigid requirements of the MARPOL Guidelines, with the exception of the assumption that all cargo is lost during damage to the side hull. The AUPS mitigates oil spill during a side hull damage. The results show, for either minor or major damage cases, that the cargo loss that would occur without the use of AUPS is reduced by 50 to 80 percent when AUPS is active.

Risk based Design Analysis: The AUPS design analysis is performed in the context of operational risks and reliability of the system and its components. A preliminary reliability analysis was performed based on the assumptions that hardware used is to be standard marine hardware, and that the controls electronics are to be essentially standard industrial grade. A system reliability of approximately 0.997 is achievable using some redundancy.

Structural Analysis: A structural analysis on a 267,000 dwt tanker with AUPS was performed by the American Bureau of Shipping (ABS). The analysis includes incremental underpressures up to 14.2 psi, although the AUPS average underpressure requirement is about 3 psi. ABS concludes in its analysis:

> "*The analysis was performed for the purpose of obtaining the structural response for the center deck structure due to incremental levels of underpressure. As such, there is no conclusion, just a presentation of results for the use by MH Systems. However, we can state that from a structural assessment point of view the underpressure procedure is a viable system.*"

Economics Feasibility: The increase in ownership and operating cost attributable to the addition of AUPS was calculated for designs considered in the study. The acquisition costs, including logistic costs plus present net worth of operating costs over 10 years, is $6,617,000 and $7,844,000 for tankers - 70,000 dwt and 300,000 dwt respectively. The reason there is very little cost increase with very significant deadweight increase is because the basic equipment does not scale upwards – only the distributive systems.

The dollar cost per barrel saved for the probabilistic distribution of side and bottom are $1277/bbl and $277/bbl for tankers - 70,000 dwt and 300,000 dwt respectively. "The cost per barrel of oil saved" is a measure of evaluating transportation costs and effectiveness of major spill prevention measures. The cost effectiveness of the system increases significantly with increase in displacement since the system has high fixed costs and small variable costs.

Recommendation & Concluding Remarks:

This report reflects the final phase of the extensive testing that has occurred during the last 12 years on the American Underpressure System (AUPS). The results of the full-scale tests, design and analysis efforts are sufficiently conclusive to justify and support rulemaking by the United States Coast Guard (USCG). The AUPS concept is sufficiently mature to justify operational trial in actual service. *And of utmost and timely importance, AUPS provides valuable damage protection to tankers endangered by hostile enemy action.*

We believe that all the conceivable concerns expressed by the USCG regarding AUPS, directly, by inference (or anecdotal), have been addressed. The AUPS is safe, reliable and unusually cost effective. After years of extensive analysis, research and tests, we did not find any scientific or technical evidence to suggest otherwise.

Structural Safety: There is absolutely no scientific evidence that underpressure within the operational limits of the AUPS will overstress the structure of the tanker. The American Bureau of Shipping (ABS) was tasked to conduct the structural analysis and states categorically … *"However, we can state that from a structural assessment point of view the underpressure procedure is a viable system."*

Vapor Safety: The AUPS is a closed loop system which maintains an inert gas blanket in the ullage space at all times and re-circulates the ullage gas via a Blower, Salt Water Heat Exchanger, and Modulating Valves, with controls to maintain an underpressure at a selected value. *This is a sensor driven, totally automatic system and would not permit either the ullage gas oxygen level or underpressure to reach an unsafe level.*

Evaporation under negative pressures: Laboratory tests and analysis show that in a closed system such as AUPS, equilibrium between liquid and gas/vapor components is reached at moderate hydrocarbon partial pressures (i.e. underpressures). *Very little evaporation occurs in a closed loop AUPS, if external perturbations due to fluctuating diurnal temperatures are kept in check.* We have then applied these findings to solve another problem – prevent or minimize VOC (Volatile Organic Compound) emissions during transport of crude oil. This is a technical breakthrough – the adverse environmental and economic losses caused by VOC emissions from crude oil tankers worldwide are significant.

Cost Effectiveness: The AUPS is economically viable and cost effective. There are no other systems, including double hulls, that can match the cost effectiveness of AUPS. The extensive full-scale tests, laboratory tests, analysis plus design detail approaching contract design plus economic analyses, risk and reliability analysis have validated the technical aspects of AUPS and significantly improved the attractiveness of the system.