



## Multi-Mission Maritime Aircraft Mission Area Analysis

*William M. Kroshl and Scott R. Osborne*

**T**he Multi-mission Maritime Aircraft Program is developing a weapon system to accomplish multiple missions within a Joint battle space. The specification for this system is performance-based. The first step in developing such a specification is to identify the mission areas and perform a “Strategy-to-Task” analysis to ensure that all performance specifications fully support the aircraft missions and the strategy of U.S. armed forces. This article discusses the use of the “Quality-Function-Deployment” (QFD) process for this mission analysis, the use of simulation techniques to update and extend an existing large-scale collaborative QFD analysis, and the sensitivities of the QFD process.

### INTRODUCTION

The goal of the Multi-mission Maritime Aircraft (MMA) Program is not merely to develop a replacement for the aging P-3 aircraft. The task is much more complex and subtle than a 1-for-1 airframe replacement. The objective is to develop a weapon system that will accomplish multiple missions within the Joint battle space. These missions include armed maritime reconnaissance, undersea warfare, anti-surface warfare, and strike warfare. MMA must be considered as an integral part of the Joint structure of naval, land, and aerospace forces, with interfaces to land, sea, air, and space systems. Articles elsewhere in this issue on mission analysis (Guarneri) and Design Reference Missions (Lilly and Russell) discuss key elements in the process of converting mission requirements into quantifiable and testable performance parameters (attributes) such as mission radius, payload, and endurance. The Mission Area Analysis discussed in this article served as a precursor to the current MMA mission analysis and provided some of the context for the Design Reference

Mission. In addition, it helped to identify the critical attributes of the MMA system and to ensure that all potential mission areas were identified. These mission areas and attributes were then related to the National Strategy as well as standard Strategic, Operational, and Tactical Tasks as described in the Unified Joint Task List (UJTL).

The UJTL is a standard listing of Warfighting Tasks that can serve as an analytic framework for mission analysis. The list is organized in a hierarchical fashion: Strategic Tasks (ST) are broken down into Operational Tasks (OP), which are further broken down into Tactical Tasks (TA). Each task has a numerical designation. These are Joint Tasks across all the services. The Navy has further defined an entire hierarchy of Navy Tactical Tasks (NTA) that support the UJTL while providing a finer granularity to the Tactical-level Tasks from a naval perspective. Once the tasks are broken down into manageable blocks they are assigned to units at various levels within the operating forces.

The process used to link STs through a chain of related OPs and TAs to aircraft attributes in the Mission Area Analysis is called a “Strategy-to-Task” methodology.

A Mission Area Analysis<sup>1</sup> for a new land-based maritime patrol aircraft had already been conducted in 1998 when the program was envisioned to provide airlift, airborne command post functions, and land-based maritime patrol using a common airframe. (Throughout the rest of this article this work will be referred to as the “previous analysis.”) The MMA Program Office requested that we update the previous analysis and determine the validity of existing results for the current program of record, which no longer included airlift and airborne command post functions.

The previous analysis made extensive use of panels of experts assembled from Fleet squadrons and major staffs. The information gleaned from these panels was analyzed and used to populate a series of related matrices, which were linked using a “Quality-Function-Deployment” (QFD) process (see the boxed insert).

Another assignment for the current Mission Area Analysis was to provide a path of linkages, starting with the National Strategy and ending with specific attributes of the MMA system. To complete this analysis in a timely and cost-efficient manner, we built upon the previous analysis to the maximum extent possible and

used the existing Joint Task (UJTL) Framework. As depicted in Fig. 1, this framework was one side of the current analysis, and the previous study (once it was verified) formed the second side, each representing half of the complete chain. Broadly stated, our work was to provide the linkage between the two segments and then to ensure that the result was applicable to the current MMA Program.

Adjustments to the previous analysis were required. Some data that were no longer applicable to the current program were deleted, and some existing data were extended in a manner consistent with the previous analysis without going through the entire QFD process again.

## ESTABLISHING LINKAGES

We began by reviewing all the NTAs within the MMA mission area and identified 47 as tasks that MMA would perform in either a principal or supporting role. We then linked these NTAs back to their “parent” STs using the complete chain of Joint TAs and OPs.

As discussed in the boxed insert, the previous analysis used a series of related matrices developed during the QFD process to link scenarios, aircraft tasks, aircraft functions, and aircraft attributes for a variety of

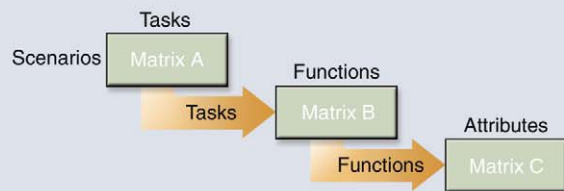
### THE QUALITY-FUNCTION-DEPLOYMENT (QFD) PROCESS

The Mission Area Analysis of new aircraft conducted in 1998 used the QFD method to link scenarios, tasks, functions, and attributes. We describe the process in sufficient detail here to provide the highlights of the methodology.

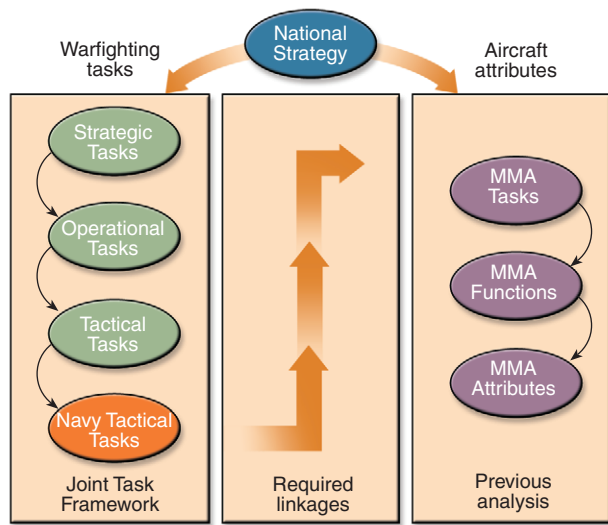
The heart of the QFD analysis involves a series of matrices that are linked as shown in the figure. Each matrix relates one category of information to another, such as Tasks-to-Functions or Functions-to-Attributes. The matrices are related to one another by a series of inner product calculations. Entries in the matrices consist of “weights” showing the strength of the relationship between row and column values. If the rows of one matrix were all functions, and the columns were attributes, then the entries would show the strength of the relationship between functions and attributes.

The entries in the matrices were developed by a panel of experts chosen from various groups within the MMA community (e.g., Fleet users, staff representatives) over a series of four meetings in 1998. Thus, the entries represent the consolidated opinions of the experts, gathered in a controlled manner, and quantified in such a way as to facilitate analysis. The nonzero entries for weights were either 1, 3, or 9, with the smaller numbers denoting a weaker relationship between the quantities. A column vector was also associated with each matrix. This vector had one entry for every row in each matrix. This number represented the relative weight of each row in the matrix. The weights in the first column vector (the scenario vector), corresponding to the rows in Matrix A, represented the collective opinions of the

experts regarding the importance of each scenario. Each row of the matrix represented a Scenario, and each column represented a specific MMA task. The inner product of the scenario vector was calculated with each column vector of Matrix A. The row vector that resulted captured the interaction between scenarios and tasks. The transpose of this vector became the task vector that interacted with Matrix B. In Matrix B, the rows referred to tasks, and the columns to functions. The inner product of this task vector was calculated with each column vector from Matrix B to form another row vector, the function vector. The transpose of this vector became the function vector that interacted with Matrix C. In Matrix C, the rows referred to functions, and the columns to attributes. The inner product of the function vector with each column vector in Matrix C produced the final row vector. Each entry in this vector was associated with a single aircraft attribute. The relative values represented the relative importance of each aircraft attribute, taking into account the scenarios as well as the various tasks and functions associated with the MMA.



Matrices linked using the QFD approach.



**Figure 1.** Linkages between the National Strategy, warfighting tasks, and aircraft attributes. APL’s contribution was to update a previous analysis and provide the required linkages between the Joint Task Framework and the current study.

missions. These missions, however, were a superset of the MMA missions in the current program. To use this information in our analysis, the following actions were required:

- Extract the relevant MMA missions from the previous analysis, setting aside information for tasks that were not part of the current MMA mission. After selecting and removing these missions, ensure that their removal did not distort the results of the current analysis.
- Update the previous analysis as required, ensuring that all appropriate MMA missions were properly represented and included.
- Ensure that the scenarios used in the previous analysis were still relevant to current strategy and planning doctrine.

The previous analysis was based on a series of scenarios interacting with a series of tasks. Unfortunately, these scenarios were not the current planning scenarios from the Defense Planning Guide (DPG), nor were the tasks taken from the current UJTL. However, all of the essential attributes of the scenarios used in the previous analysis are included in the current, approved DPG scenarios. Fortunately, no major scenario element from the current guidance was missing from the earlier work. After a thorough review, we considered that the existing QFD scenarios provided an adequate characterization of the DPG scenarios within the context of the MMA Program analysis.

In the previous analysis there were 83 different warfighting tasks. Out of these 83 potential tasks, 49 were identified as applicable to the current study. Recall that

the 1998 analysis focused on mission analysis for an aircraft that would function in maritime patrol, airlift, and airborne command post roles. Of these 49 tasks, the panel of experts concentrated on 19 that they considered “opportune,” i.e., those most likely to be positively impacted by the MMA.

At this point, we essentially had the two halves needed for our analysis, one part consisting of the linkages of tasks at the various levels of warfare (strategic, operational, and tactical), and the second part an updated analysis of the aircraft attributes based on the previous QFD study. The interface between them consisted of the 49 QFD-identified tasks on one side and the 47 NTAs identified through our update effort on the other. A closer examination of the two halves showed a high degree of correspondence.

Both the NTAs and the QFD tasks were arranged in a hierarchal fashion. Some adjustments were made to account for the structural differences between the two systems of task organization. Although there was not a “clean” 1-for-1 correspondence between the two sets of tasks or levels of tasks, we eventually were able to identify a good correspondence between the applicable tasks of the QFD study and the tasks we had identified from the NTA list. The analysis provided the critical link between the QFD study and our Strategy-to-Task effort. The scenario matching effort described above also ensured that both studies were built upon a consistent base.

## UPDATING MATRIX VALUES

After completing the interface between the two chains, we now had a complete linkage from STs to aircraft attributes. However, because some new tasks introduced in this mapping were not considered in the previous QFD study, we needed to update some entries in the QFD matrices to complete and validate the linkages. We began the validation process using our expanded task list and updated scenario descriptions, retaining the same aircraft functions and attributes used in the previous QFD analysis. The Scenario-to-Task weighting matrix (Matrix A in the previous QFD study) had complete entries for all 83 tasks, so these data were readily available. In the Task-to-Function matrix (Matrix B in the previous QFD study), approximately 18% of the entries that were needed to complete all the required linkages had not been considered in the previous QFD study owing to the increased set of tasks that we evaluated as being required. Rather than assemble a large group of users and reopen the entire set of QFD matrices for review, we assembled a small internal team of experts and used their inputs for the entries (weights) assigned in the matrix.

Even though these actions provided a complete set of linkages, we were left with two major concerns:

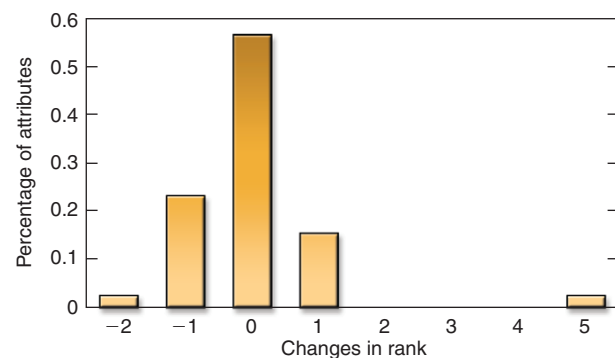
(1) Did the removal of tasks distort the results? (2) How sensitive were the results to the values that were inserted into the Task-to-Function matrix by the small in-house group of experts? These values did not have the same “pedigree” as the rest of the weights in the study, and we were concerned that the small group of analysts might have introduced a distortion into the work. To address these concerns we conducted several different sensitivity analyses, some of which included simulation techniques.

The end result of the previous QFD study was a series of scores, normalized to a percentage, that ranked the relative importance of the aircraft attributes. To assess the effect of removing mission tasks, we compared the results of the previous QFD study to results obtained using the same matrices with the tasks deleted, but without the new entries added. The actual variation was very small; using a root mean square (RMS) calculation, the average change was 0.3%. This change was smaller than the smallest individual attribute score.

A more significant result was obtained through an examination of the ordinal changes in the data ranking. The order of more than half of the attributes did not change at all, and only two of the attributes changed position by more than one rank (Fig. 2). The changes that did occur were consistent with the removal of mission areas. Based on these results, we determined that those missions could be removed without compromising the validity of our Strategy-to-Task effort.

## SENSITIVITY ANALYSIS OF RESULTS

The sensitivity analysis for the newly added values was a difficult challenge. To remain cost-effective, we relied on simulation techniques to help us see the extent of the impact of our additional data and determine how variations in the added data affected the final analysis. If the added data had a major influence on the overall results, the uncertainty of our analysis would increase. We performed two different stochastic sensitivity analyses (Case A and Case B) and a deterministic approach



**Figure 2.** Ordinal data results: one attribute shifted by +5 and one shifted by -2; all other ordinal shifts were either 0 or 1.

(using entry values of 1, 3, or 9) to delineate the limiting cases.

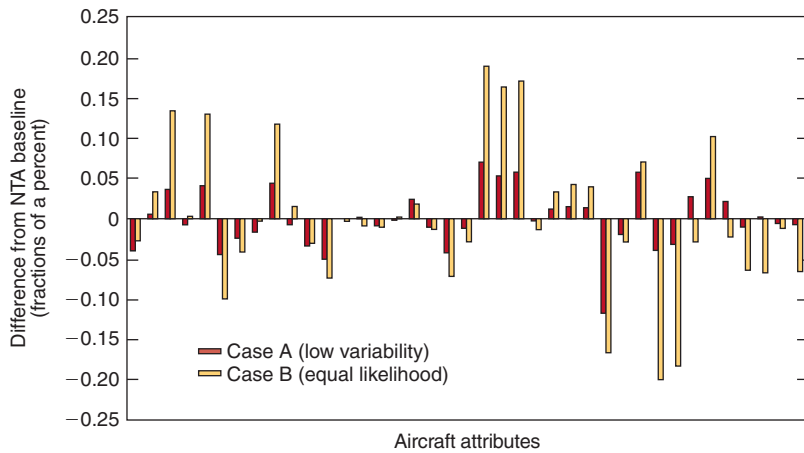
Of the three matrices used in the analysis, we added values only to Matrix B (Task-to-Function). This matrix expressed the strength of the interaction between combinations of Tasks-to-Functions with four possible values: null (no interaction), 1, 3, or 9, with larger numbers showing a stronger interaction. Approximately 48% of the entries were blank. We added approximately 18% of the total number of nonzero entries. To assess this sensitivity we developed a stochastic model where the values that were added were allowed to vary, reflecting the uncertainty in the values. It is important to note that none of the values assigned in the previous analysis were changed in any way: we only varied values that were added by us.

Two different probability distributions were used for the values added, reflecting different assumptions. The values represented the strength of the relationship between the tasks and functions. The first case (Case A) assumed that the weights assigned by the small panel of experts were a fairly accurate predictor of what the values would have been from the full study panel. The second case (Case B) assumed that values of 1, 3, and 9 were equally likely, regardless of the values we had assigned. After varying those values using 10,000 runs as the sample size, we looked at the changes in the final scores for the MMA attributes that resulted from the output matrix, Matrix C (Function-to-Attribute). Our baseline was the study with all values set to our recommendations in Matrix B. These final results were normalized to a score of 100%. The RMS averages for the differences from the baseline case were minimal. The largest average variation was less than 0.2%. These results are shown in Fig. 3.

Using the deterministic approach, we looked at limiting cases by having all the values we inserted take on values of 1, 3, or 9. The deterministic results showed a similar degree of invariability. Regardless of the values we assigned for our entries in the Task-to-Function matrix, the largest average variation was less than 0.52%. These results are shown in Fig. 4.

These results were intriguing. No matter how we manipulated the added values of Matrix B, the greatest difference observed was less than 0.52% of the normalized score. From this we concluded that the results were very insensitive to the values inserted into Matrix B. We wondered if some interaction among the three matrices resulted in this unexpected stability or if it was related to the specific tasks we chose to add from Matrix A, or some other unanticipated dependency.

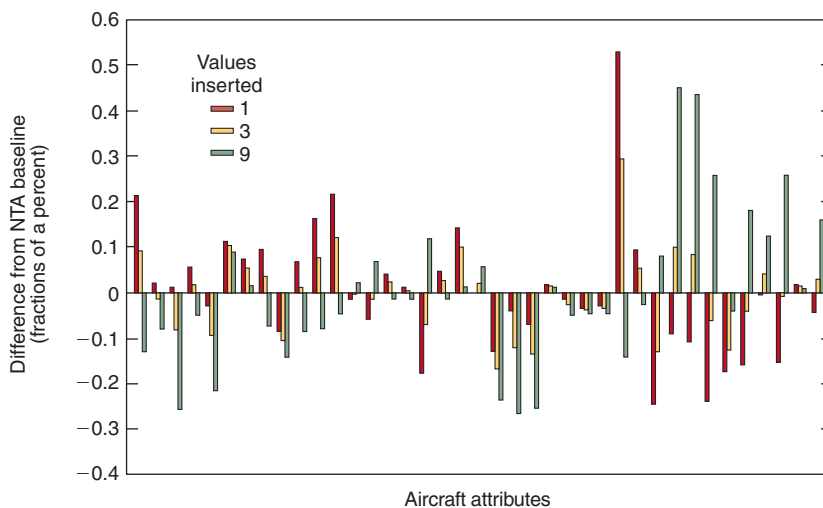
To obtain some insight into the stability of the models, we conducted a further analysis: we observed what happened when we selectively removed tasks from Matrix A, and then observed the average change in values for the final results from Matrix C. Because each of the



**Figure 3.** Results were insensitive to changes in values added to Matrix B using stochastic variation. Only 1 attribute in Case A changed more than 0.1%; 11 attributes in Case B changed by that much.

tasks in Matrix A had a different weight, we also looked to see if the specific task removed mattered. We pursued three different approaches. For the first two, we ranked the tasks from highly ranked to lower ranked. In the first case we began by removing the highest-ranked tasks first, and then continued to remove them in order until only one task was left. In the second case, we began by removing the lowest-ranked tasks first, and then continued until only the most highly ranked task was left. In both cases, we compared the average difference from the baseline case against the percentage of the total “value” of the tasks (measured by relative weight from Matrix A) and graphed the result. This gave us our limiting cases.

Finally, we took a stochastic approach and randomly removed items totaling a fixed percentage, varying it from 5 to 95%. At each value we ran 5000 trials. The results are shown in Fig. 5. From this figure,



**Figure 4.** Results were insensitive to limiting deterministic cases where all added values were either 1, 3, or 9. Only six attributes changed by greater than 0.25% for added values of 9; only one changed that much for each of the other two entry values.

we see that once about 40% of the values of the tasks in Matrix A are fixed, there is very little variation (less than 10%) in the final weights of the results.

### INSIGHTS GAINED

The original purpose of our effort was to update the previous analysis and see if significant changes resulted from the change in missions and passage of time since the original QFD-based study was performed. Our work showed that the changes were minor and that these minor changes were so small relative to the sensitivity of the analysis tools used that the results could

stand unchanged. Our secondary purpose was to provide a logical data flow from the Joint Task structure down to the specific MMA attribute. By putting all the data from these matrices into a relational database we gave program managers a powerful analytical tool that can quickly show relationships both up and down the Strategy-to-Task linkage.

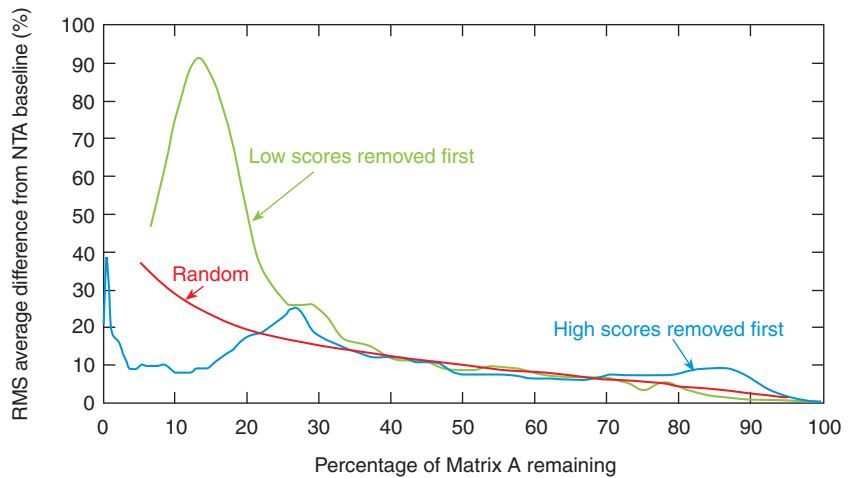
Almost 5000 complete Strategy-to-Task chains result from looking at the high-level (all strength “9”) interactions among the matrices. This database allows the analyst to quickly answer questions such as, “If we reduce the range of the aircraft, how will that affect my ability to meet Joint Task requirements?” While the database cannot give the numeric answer, it can provide the complete list of tasks that would be affected, from ST right down to NTA.

All simulations in this analysis were done using @Risk, a commercial “add-in” to Excel. It allows for rapid prototyping and provides results without a great deal of additional coding.

### SUMMARY

This work provided several essential and fundamental analytic results for the MMA Program. The first was to confirm the results of the previous Mission Area Analysis. These results were found to be invariant despite the changes in planning scenarios, aircraft roles, and analytic task hierarchy. An added benefit was that this confirmation was completed at lower cost and in much less time than it would have taken to perform a completely new analysis. The second result was to

provide complete traceability from individual aircraft attributes back to the TAs that the weapons system will be performing, and from those tasks back to the Joint STs that the system supports. This methodology yielded useful insight into the sensitivity of a Mission Area Analysis to changing conditions or assumptions. It also provided a way to quickly update the existing QFD analysis to reflect changed conditions, additions, or deletions. These techniques allow for greater flexibility and more robust decisions, with less time spent on analysis.



**Figure 5.** Sensitivity to partial removal of Matrix A showing that once 40% of Matrix A values are in place, the results are essentially fixed.

#### REFERENCE

- <sup>1</sup>"Multi-mission Maritime Aircraft Quality Function Deployment," Mission Area Analysis Final Report, 30 Sep 1998.

#### THE AUTHORS



WILLIAM M. KROSHL earned a B.A. in economics from Northwestern University in 1975 and an M.S. in operations research from the Naval Postgraduate School in 1988. He joined APL in 1997 and is currently an operations research analyst in the National Security Technology Department. He has participated in a number of studies of conceptual systems, focusing on affordability, risk analysis, military utility, logistics analysis, and system utility. Before joining APL, Mr. Kroshl served for 21 years on active duty in the Navy and retired with the rank of Commander. While on active duty, he served on the faculty of both the Operations Research Department, Naval Postgraduate School, Monterey, California, and the Mathematics Department, U.S. Naval Academy, Annapolis, Maryland. He spent over 12 years on sea duty on five different Navy surface ships. His e-mail address is [william.kroshl@jhuapl.edu](mailto:william.kroshl@jhuapl.edu).



SCOTT R. OSBORNE is a member of APL's Principal Professional Staff in the Power Projection Systems Department's Aviation Systems Group. He received a B.S. in electrical engineering from The Stevens Institute of Technology in 1970 and an M.S. in electrical engineering from the JHU Whiting School of Engineering in 1973. Mr. Osborne has been a member of the Multi-mission Maritime Aircraft Integrated Product Team since 2001 and a full-time member of the Off-Board Systems Team where he contributes to the development of the MMA Operations Requirement Document and C4I Support Plan. He has also conducted C4ISR architecture analyses for the Joint Strike Fighter Program Office. His e-mail address is [scott.osborne@jhuapl.edu](mailto:scott.osborne@jhuapl.edu).