Journal of Aeronautics & Aerospace Engineering
ISSN: 2168-9792
Amirreze et al., J Aeronaut Aerospace Eng 2013, S1
DOI: 10.4172/2168-9792.S1-001
Research Article Open Access

A New Systematic Approach in UAV Design Analysis Based on SDSM Method

Kosari Amirreze[1]*, Dolatabadi Marzieh[1], Sanii Foad[1] and Asadi Fatemeh[2]

[1]*Department of New Sciences and Technologies University of Tehran, Iran*
[2]*Sharif University of Technology, Iran*

Abstract

The purpose of this paper is to implement a new systematic methodology for conducting conceptual design studies of an Unmanned Aerial Vehicle (UAV). During the design phase of any system, many variables, tasks, parameters and components should be taken into account. In this work we employ a system engineering powerful analysis technique based on Sensitivity Design Structure Matrix (SDSM). DSM provides a simple, compact, and visual representation of a complex system which supports innovative solutions to decomposition and integration problems. In this work, SDSM method, considered as a powerful technique in design analysis of complex systems, has been employed in design analysis of a light weight UAV. Applying this effective disintegration methodology, all the design parameters and their inherent interconnections could be specified and if the design structured matrix elements confront changes, based on any changes in internal or external design drivers, its propagating effects on the whole system concept could be directly traceable which in turn lead least effect on the total system variations. Finally this paper shows that disintegrated, sections-based design process architecture, like that used for the Sirang, as a light weight UAV, is optimal for product development, and it results in a low cost architecture for development of UAVs.

Keywords: Sensitivity design structure matrix; UAV; Conceptual design; Complex system

Introduction

Aircraft development process involves identification of its requirements, listing of asks to accomplish, and identification and allocation of required resources for its successful execution. Generally the life cycle of an aerial mission progresses through four phases:

1- Design Phase

2-Production

3-Operations

4- Support

Design process of an aircraft system prior to its production stages can be decomposed into three phases: conceptual design, preliminary design and detailed design, which are traditionally executed in that sequential order. In brief, conceptual design results in a broad definition of the flying mission and its components and finally, it results in feasible aircraft concepts polar, tailored to the established driving requirements, refined through higher fidelity analyses in preliminary design before the complete specification is finalized in detailed design stage. The formal design phase, results in detailed definition of the aircraft components and development of test hardware and software.

In the operations and support phase, the day to day operation of the flying system, its maintenance and support, and finally its disposal or recovery at the end of mission life will be considered.

The main challenge in designing procedure of an aircraft is its multi-disciplinary nature. This is characterized by degrees of influences that each design discipline has on the others, such as how aerodynamic lift and yaw moments, drive the sizing of horizontal stabilizer and rudder, which consequently affect flight control systems.

According to what mentioned above, a UAV, called Sirang, has been decided to be redesigned using Design Structure Matrix (DSM). Using this method, rework cost, product and development could be investigated and optimized. For example The result of implementing the DSM approach for Light Combat Aircraft (Navy) at Hindustan Aeronautics Limited, India, (in aircraft design) showed primary benefits of 75% reduction in routine activities, 33% reduction in design cycle time, 50% reduction in rework cost, and 30% reduction in product and process development cost of aircraft [1].

The design structure matrix method originated in the 1960s, when several efforts were devoted to solve different systems of equations. Donald Steward (1981) first coined the term 'design structure matrix' and applied this concept to system design. The method gained more credibility due to the results of several researches done at the Massachusetts Institute of Technology in 1990s [2,3].

As a brief introduction, the DSM is a succinct way of addressing the modeling issue by re-structuring the flow of information in a complex system design, [2]. On the other hand, the DSM is an information exchange model which provides an elegant representation of the interactions that exist between the elements of a decomposed system or product [2]. The use of the DSM to represent the physical, task, and organizational views of engineering systems has expanded in recent years as there are over one hundred papers that demonstrate the value and/or extend the use of this matrix [3].

There are two main categories of DSM; namely, static and time-based (Figure 1). Static DSMs represent existing system elements, such as components of product architecture or groups in an organization,

***Corresponding author:** Kosari Amirreze, Assistant Professor, Department of New Sciences and Technologies University of Tehran, Iran, E-mail: Kosari_a@ut.ac.ir

Received March 21, 2013; **Accepted** April 27, 2013; **Published** May 05, 2013

Citation: Amirreze K, Marzieh D, Foad S, Fatemeh A (2013) A New Systematic Approach in UAV Design Analysis Based on SDSM Method. J Aeronaut Aerospace Eng S1: 001. doi:10.4172/2168-9792.S1-001

Citation: Amirreze K, Marzieh D, Foad S, Fatemeh A (2013) A New Systematic Approach in UAV Design Analysis Based on SDSM Method. J Aeronaut Aerospace Eng S1: 001. doi:10.4172/2168-9792.S1-001

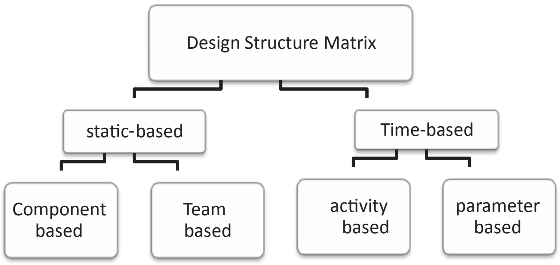

Figure 1: Design Structured Matrix (DSM) taxonomy [2].

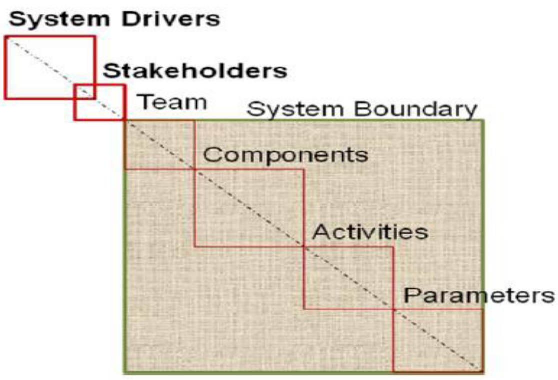

Figure 2: Representing relationships between endogenous and exogenous system by DSM extension [4].

simultaneously. In time-based DSMs, the ordering of the rows and columns indicates a flow through time; upstream elements of a process precede downstream elements [2].

This section develops an architecture options screening process by means of five steps, originally used in system architects and system engineering. Each step is a necessary and distinct purpose in the screening process.

STEP 1: Define the set of potential operational scenarios and score each scenario for its likelihood and opportunity.

STEP 2: Determine the unique functional requirements associated with each scenario.

STEP 3: Complete a functional-to-physical mapping of functional requirements to physical design parameters by populating an expanded design structure matrix.

STEP 4: Investigate a sensitivity analysis of the sensitivity of design parameters to changes in system functional requirements, and normalize final sensitivity-DSM.

STEP 5: Apply an appropriate matrix clustering algorithm which could divide the sensitivity-DSM into sub-sections of highest sensitivity with minimal interaction between clusters [4].

The extension of the DSM beyond the system boundary enables additional insight into the system behavior affected by the stakeholders and other external system drivers (Figure 2). The relationship between endogenous and exogenous variables is explored as a mean to understand how each scenario-generated functional requirement affects the physical design variables.

Generally, stakeholder is a person, organization, rules, etc., which could affect the working flow condition and impose new limitations on our designs. Since the Sirang UAV has been designed to participate in a student competition, the main and the most important stakeholders are the rules and conditions of the competition. Furthermore, this UAV has been designed so in order to be used by the pre-selected team sponsor who could be considered as the second stakeholder. The design team also intended to design a system which could be offered to prospective customers such as air monitoring companies, environmental and fire fighters organizations, so some special limits such as minimum and maximum altitude in urban areas may be imposed as new requirements to the design by these stakeholders.

As it can be seen in figure 3, stakeholders has been separated from the defined system boundary due to the reality that they only impose limitations to our SDSM system and do not accept any input but their outputs have great influence on our system boundary.

As it has been already mentioned, the DSMs with higher priority should be placed in higher positions in system boundary and since the team DSM is the most important DSM in our system boundary, it has placed in the first stage and the other DSMs introduce one after each other based on the defined process hierarchy. In this way the output of each type of DSM is the input of the next stage. So should any fault occur in any subsystem, the problem could be easily traced to find and solve the exact source of the fault propagation. As an example, imagine that, there is some problem in aileron actuator which is defined as an element of the component-based DSM. According to the component-based DSM the aileron may be influenced by different component parameters such as wing, servo motors, autopilot and etc. After checking these components, we should check if these components are influenced by the team-based DSM, placed before the component DSM. So in our example, if the fault source might be occurred in the Team DSM then, the team should reconsider its design due to the activity-based DSM. In this examined case, since the output of the Team DSM has been changed, all parameters in the system boundary which has been influenced by the aileron re-design will be changed. This results in that only the parameters which are in relationship with the aircraft aileron will be changed and the other parameters may be remained unchanged. Therefore, applying this procedure, significant reduction in routine activities, design cycle time and rework cost could be expected as the main advantages of this methodology.

Team-Based DSM

This is more workforce-oriented, is based on the information flow

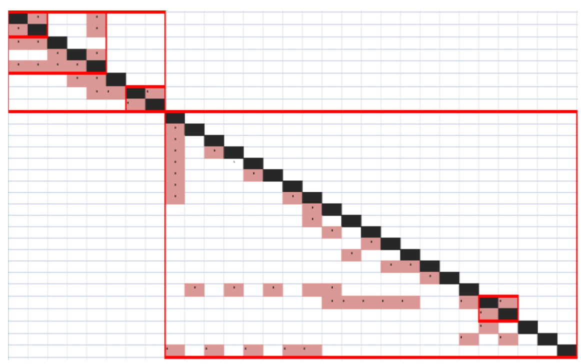

Figure 3: Sensivity Design structure matrix Developed for Sirang UAV.

Citation: Amirreze K, Marzieh D, Foad S, Fatemeh A (2013) A New Systematic Approach in UAV Design Analysis Based on SDSM Method. J Aeronaut Aerospace Eng S1: 001. doi:10.4172/2168-9792.S1-001

Team-based	1. Structure 2. Aerodynamics 3. Flight Dynamics and Control 4. Electronics 5. Construction 6. Communication 7. Ground station 8. Image Process
Component-based	9. Wing 10. Aileron 11. Vertical tail 12. Rudder 13. Horizontal tail 14. Elevator 15. Fuselage 16. Boom 17. Sensors 18. Camera 19. Micro controller 20. Data transmitter 21. Video transmitter 22. Antenna 23. Ground station 24. Autopilot 25. Battery 26. Motor 27. Battery charger 28. Parachute 29. Packaging
Task-based	30. Determination of mission 31. Data Base Bank (DBB) 32. Estimation of battery weight 33. Finding the allowable value for empty weight 34. Comparing empty weight with DBB 35. Sensitivity studies 36. Drag of Lift zero 37. Induced drag 38. Drag polar 39. Sizing the performances parameter of flight 40. Matching of all sizing requirement 41. Choosing the Design Point 42. Choosing the motor and it's propeller 43. Calculating the real battery weight 44. Compare the battery weight with estimated Battery weight 45. Selection of the overall configuration 46. wing plan form design 47. locating and sizing of lateral control 48. Verifying clean Clmax 49. Vertical Tail Design 50. Locating and sizing of Rudder 51. Horizontal tail Design 52. Locating and sizing of Elevator 53. Design of fuselage layout (cross section, Payloads, Battery, servos, …) 54. Aerodynamically Design of Fuselage 55. Choosing the material of the UAV with respect to empty weight 56. Choosing the best Landing mechanism 57. Construct V-n diagram 58. Choosing the subsystems for covering of the mission 59. Weight and Balance Analysis 60. Calculating of wet Area with CATIA 61. Performance analysis 62. X-Plot (longitudinal, Directional) 63. Stability and Control Analysis 64. FDIR(fault detected and isolation and recovery) 65. Costs Managements 66. Manufacturing 67. Flight tests

Parameters-based	68. Altitude 69. Range 70. Loiter 71. Endurance 72. Payload weight 73. Total weight estimation 74. Technology parameter 75. Empty weight 76. Total weight 77. Climb speed 78. Loiter speed 79. Cruise speed 80. Stall speed 81. Approach speed 82. Parachute type 83. Parachute fibre 84. Parachute Width to length ratio 85. Number of parachute line 86. Length of parachute line 87. Weight of parachute 88. Sea level temperature 89. mission altitude temperature 90. Air density in sea level 91. Air density in mission altitude 92. Correlation coefficient 93. Wet Wing area 94. Equivalent parasite area 95. Zero lift drag coefficient 96. Oswald ratio 97. Wing span 98. Wing chord 99. Aspect ratio 100. Induce drag 101. Parasite drag 102. Rate of climb 103. Time of climb 104. Lift to drag ratio in cruise phase 105. Lift to drag ratio in loiter phase 106. Manoeuvre speed 107. Manoeuvre radius 108. Earth gravity acceleration 109. Load factor 110. Rate of climb parameter 111. Power index 112. Matching chart 113. Wing area 114. Max power requirement 115. Power plants 116. Number of battery pack 117. Total pack weight 118. Engine weight 119. Number of blade 120. Wing position 121. Airfoil Lift coefficient in small angle of attack 122. Airfoil lift to drag ratio in small angle of attack 123. Airfoil camber 124. Airfoil stall angle 125. Airfoil angle of attack in zero lift 126. Thickness of airfoil 127. Wing airfoil 128. Max lift coefficient 129. Incidence angle 130. Taper ratio 131. Span of aileron 132. Chord-aileron 133. Volume of vertical tail 134. Vertical Tail airfoil 135. Vertical Tail thickness airfoil 136. Vertical Tail taper ratio

Citation: Amirreze K, Marzieh D, Foad S, Fatemeh A (2013) A New Systematic Approach in UAV Design Analysis Based on SDSM Method. J Aeronaut Aerospace Eng S1: 001. doi:10.4172/2168-9792.S1-001

	137. Vertical Tail position
	138. Vertical Tail span
	139. Vertical Tail chord
	140. Vertical tail aspect ratio
	141. Span of rudder
	142. Chord of rudder
	143. Volume of Horizontal Tail
	144. Horizontal Tail airfoil
	145. Horizontal Tail thickness airfoil
	146. Horizontal Tail taper ratio
	147. Horizontal Tail position
	148. Horizontal Tail span
	149. Horizontal Tail chord
	150. Horizontal Tail aspect ratio
	151. Fuselage length
	152. Radius of fuselage
	153. Boom length
	154. Boom diameter
	155. Center of mass position
	156. Position of aerodynamic center
	157. Static derivative
	158. Stability coefficient
	159. Control coefficient
	160. Cost of subsystem
	161. Cost of material
	162. Cost of manufacturing
	163. Altitude of Flight test site
	164. Weather of Flight test site
	165. Flight test performance parameter

Table 1: SDSM elements distinguished for Sirang UAV.

between different organizational entities involved in the UAV project. Matrix elements which can be analyzed are individual, groups and their participation in the project. According to main scenario team-based DSM in this project contains eight elements, depicted in table 1.

Component-Based or Architecture DSM

Used for modeling UAV system architectures based on components and/or subsystems and their relationships.

Activity-Based DSM

This DSM defines a compact, matrix representation of the UAV project network. The matrix contains a list of all constituent activities and the corresponding information exchange patterns. That is, which information pieces (parameters) are required to start a certain activity and where the information, generated by that activity, feeds into (i.e. which other tasks within the matrix utilize the output information). The DSM provides insights into how to manage an aircraft design and highlights needs and requirements, task sequencing, and iterations. Therefore using this approach, we could save time, energy and cost. Task-based DSM with all 38 tasks, which are the requirements of UAV design, is introduced as follows.

In the first step the UAV mission specification and mission profile should be determined. Sirang, the designed UAV, has a special mission, It should fly for at least one hour in two different altitudes with 3,000 ft difference in altitude, and carry a box with the weight of 2.5 (kg) as the main payload. According to this mission, a Data Base Bank (DBB) of UAVs using electrical engine has been selected, Therefore One important task is the weight of the battery pack which should be estimated from DBB. Empty weight of the aircraft is also estimated from DBB. By estimating battery, empty and payload weights, the total weight of the aircraft could be estimated. Now, a sensitivity analysis procedure should be applied to deliberate and consequently to demonstrate the validity of the available estimated parameters. Plotting the matching chart is one of the important goals of the conceptual aircraft design.

For some airplanes the mission task demands some certain value (like stall and cruise speed, climb, loiter or manoeuvre sizing,…) so for plotting the matching chart these demands should be estimated first.

To size the Sirang for climb requirements, it is necessary to estimate the airplane drag polar. Estimation the drag polar, which proposed an estimated model defining the flying vehicle drag force, could be referred to do two tasks including zero-lift drag and induced drag estimation. After calculating all performance sizing procedures, the matching chart could be plotted in the design plane in the next step the design point should be chosen in an acceptable area of the matching chart. This leads to next tasks of calculating the maximum power and the wing area. Now the real battery weight could be estimated using both the design point estimation stage and the kind of available batteries. In the next task, the new battery weight should be compared with the old one if these two weights don't match with each other, all these steps should be done again.

The wings of the UAV may affect so many design parameters such as efficiency, cruise distance, takeoff and landing distance, weight, aesthetics and maneuverability. So the wing positioning and sizing of the control surfaces are very important tasks in this design procedure. After finishing the wing and tails sizing tasks, the rest of airframe and all associated components could be sized and located within the design procedure task matrix.

The location of the components inside the fuselage is critical for all the aircraft and especially for this UAV because the CG of the UAV is extremely close to the neutral point and it can introduce some stability risks. In order to have an acceptable approach to the optimum efficiency in aerodynamic fuselage shape, this design is divided into two tasks influenced by fuselage aerodynamics and location, including in the task-based DSM. In many respects the appropriate choice of the materials used in the manufacturing of the components of the device, determines the success of the mission. Special attention should be devoted to the main body parts in order to achieve Durability [5]. The method of launching and recovery of the aircraft should be selected according to the mission. Another task in UAV designing is V-n diagram. The V-n diagrams are used to determine the design limit and ultimate load factors, as well as the corresponding speeds to which airplane structures are designed. Any electromechanical system requires some subsystems and equipments to support its operation. These items may be available at various levels of activity matrix [6,7].

The anticipated costs and monetary returns of the UAV should be also determined [8,9]. In order to be able to attract consumers, the Sirang, as a developing system, should be inexpensive with high performance ability. In the introduced task DSM, the final task for UAV design is the flight test activity [10]. Due to the complexity incorporating in the UAV design procedure, particularly the implementation of the experimental control surfaces and the integration of the fuel cell system, a series of flight test procedures and sequences were planned [11-13].

Parameter-Based DSM

Used for modeling low-level relationships between design decisions and parameters, systems of equations, subroutine parameter exchanges, etc in the UAV design project.

Activity- and parameter-based DSMs also differ in the scope of their representations. While an activity-based DSM models a design process, a parameter-based DSM merely documents the physical relationships between the required parameters of a design. Thus, an activity-based DSM may include reviews, tests, and coordination links that would not typically appear in a parameter-based DSM. This paper takes a more focused approach and defines a parameter as a physical property whose value determines a characteristic or behavior of a system component.

Conclusion

In this research we employed SDSM method as an effective approach for design analysis of complicated systems, to design a light weight UAV. Applying this system engineering methodology leads to visually specify different parameters and their influences on the whole system which in turn provides a better insight into the system levels hierarchy. Applying this method could help the system designer in finding the sources of faults which may happen and propagate in any phase of system mission profile and consequently try to redesign the essential parts to overcome the failure problem with a minimum time operational index. Leaving other parts unchanged, we could avoid the complex problems occurring by any change in other irrelevant parts.

References

1. Shekar B, Venkataram R, Satish BM (2011) Managing Complexity in Aircraft Design Using Design Structure Matrix. Concurrent Eng-Res A 19: 283-294.
2. Browning TR (2001) Applying the design structure matrix to system decomposition and integration problems: a review and new directions. Engineering Management, IEEE T Eng Manage 48: 292-306.
3. Danilovic M, Browning TR (2007) Managing complex product development projects with design structure matrices and domain mapping matrices. International Journal of Project Management 25: 300-314.
4. Pierce JG (2010) Designing Flexible Engineering Systems Utilizing Embedded Architecture Options. Graduate School of Vanderbilt University Nashville, USA.
5. Roskam J (1985) Airplane Design. DAR corporation, USA.
6. Raymer DP (1989) Aircraft design: a conceptual approach. American Institute of Aeronautics and Astronautics.
7. Çengel YA (2010) Fluid Mechanics. Tata McGraw-Hill, USA.
8. Xuetao Z UAV Design and Manufacture. National University of Singapore.
9. Wasson CS (2006) System Analysis, Design, and Development: Concepts, Principles, and Practices. John Wiley & Sons, USA.
10. Daly M (2010) Jane's Unmanned Aerial Vehicles and Targets Issue Thirty-Four (Issue Thirty-four). IHS Global/Jane's, Surrey, UK.
11. Selig MS (1995) Summary of Low Speed Airfoil Data. SoarTech Publications, USA.
12. Anderson J (1998) Aircraft Performance & Design. Tata McGraw-Hill, USA.
13. Knacke TW (1991) Parachute Recovery Systems Design Manual. Naval Weapons Center China Lake Ca.

This article was originally published in a special issue, **Small & Micro Aerial Vehicles** handled by Editor. Dr. Yu Gu, West Virginia University, USA