A SYSTEM APPROACH TO THE CONCEPTUAL DESIGN OF VERTICAL TAKEOFF UNMANNED AERIAL VEHICLE – REQUIREMENT ANALYSIS

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Abstract

The development and induction in service of Unmanned Air Vehicles (UAV) systems in a variety of civil, paramilitary and military roles have proved valuable on high risk missions. The missions envisaged for UAVs require a rotary wing component for missions beyond the scope of in-service fixed wing UAVs. The identified operational gaps are to be filled by Vertical Takeoff UAVs (VTUAV). An automated, generic design process is required to address the conceptual design process for VTUAVs. System approach is used to develop system structure for VTUAVs based on requirement and system analysis. The requirement analysis addresses operational, environmental, and technological issues to identify mission requirements of VTUAVs.

Introduction

The design of VTUAV needs to be visualised from a systems perspective for a holistic analysis of the operational needs & environment, technology and design processes. System approach is needed to transfer the operational needs and environment to mission requirements for the development of systems structure [1]. System engineering is the most widely used system approach for formulating system design architecture [2]. System engineering process is applied for requirement & functional analysis, design of the system architecture (synthesis) and verification of the degree to which the slated requirements have been met.

Requirement Analysis

The requirement analysis investigated the required performances or design constraints to which the VTUAV must confirm. The present and envisaged operational needs of VTUAVs comprises of global and regional requirements for the military and civil customers [2]. The operational environment of VTUAVs includes varying terrain, weather, time, situation and threat [3, 4]. The design technology of VTUAVs covers crucial redundancy, advanced communication and efficient propulsion [5]. To address the operational, environmental, and technological issues of VTUAVs, the requirement analysis needs to be subdivided as follows: a) Operational analysis – To cover the operational and environmental issues based on customers need statement; and b) Mission analysis – To cover the technological issues based on operational need.

Mission Need Statement

The requirement analysis commences with a customers "Mission Need Statement" that describes the objectives of the design. To develop a generic design process for a VTUAV a customised need statement was developed from the study of present and envisaged needs of the UAV technology [6]. The need statement is listed as below:

"The present global scenario necessitates the need to provide a responsive capability to conduct wide-area and near-real-time reconnaissance, surveillance, and target acquisition, command and control, signals intelligence, electronic warfare, and special strategic & tactical missions during peace and war times against defended/denied areas over long durations. The evolution of the hostile surface-to-air and air-to-air threat and their collective effectiveness against manned aircraft and satellites will generate unacceptably high attrition and strike-loss rates. The current systems cannot perform these missions in a timely, responsive manner in an integrated hostile air defence environment without high risk to personnel and costly systems. There is a need for a capability which can be employed in areas where enemy air defenses have not been adequately suppressed, in heavily defended areas, in open ocean environments, and in contaminated environments. Nuclear survivability is required to perform missions in a nuclear contaminated environment. The technological cost justifies the growing demand of unmanned technology in the civilian sectors of agriculture, forest, power and

research. The mission activities range from aid and monitorship, to vigilance and examination over the designated areas for long durations and in varied climatic conditions. The current systems cannot perform these activities without high risk to workforce. There is a need for automated systems that can arrive at mission area in short span during emergencies. Resource and fiscal allocations are forfeited for the product robustness that ensures maximum functionality with minimum resources."

Operational Analysis

The operational analysis investigated operational and environmental issues that emanated from the customised need statement. The objectives of the design and the expected capabilities of the VTUAV was analysed to formulate a set of operations the VTUAV will be involved including the environment [7].

- Operational needs: The statement stipulates global and regional needs of the VTUAV to address civil and military clientele. In broader terms it covers reconnaissance and surveillance and offensive capabilities including communications. The operational needs are categorised as follows for further detailed analysis:
  - Civilian needs: To address commercial requirements;
  - Military needs: To address defence requirements;

- Operational environment: The statement provides a broad insight into the external environment in which the VTUAV will operate. It comprises of natural and manmade environment as follows:
  - Terrain;
  - Time;
  - Threat; and
  - Weather;
  - Situation;
  - Littoral.

Mission Analysis

The mission analysis investigated the operational needs from the perspective of mission features to identify technological requirements [8]. The investigation further transformed the operational needs in the following mission categories based on their execution schedule: a) General missions – These missions address common civil and military needs; b) Special missions – These are customised civil and military missions. The mission categories are as follows:

- General missions: The operational analysis of the need statement resulted in the segregation of most widely usage of VTUAVs. These were categorised as “General missions”. These missions presented the UAV technology development and deployment on both civil and military missions. The operational analysis also provided an insight in the environmental issues. The mission environment covers varying terrain, weather, time, and situation. The various common missions identified and their features are as follows:
  - Reconnaissance and surveillance: The mission involves armed and unarmed secret vigilance over a designated territory. It comprises of passive observation at varied levels of altitude and speed, including penetration in the forward line of enemy troops when target information is incomplete or the enemy’s flank is unprotected. This is to provide information about enemy deployments, movements and selection of routes.
  - High altitude scientific research: The UAVs provide high altitude imaging to monitor topography (which out-limits the satellite wavelength bandwidth). It covers mapping of peripheral and earthy textures, including airy constituents.
  - Fire detection and monitoring: It involves the usage of multiple temperature and smoke sensitisers (heat resistant and impermeable components) for detecting and following-up fire breakouts over an operational area.

- Special missions: These are customised VTUAV missions that demonstrate the versatility of the technology. The operational environment of special missions is the degree of threat and is situation dependent, in addition to varying terrain, weather and time. The missions categorisation is as follows:
  - Civilian missions: These are unarmed missions. The potential usage of VTUAVs is in agriculture, forest, power, research and management applications. The operational environment is situation, weather and terrain focussed. The mission activities are as follows:
    - Relief and monitoring: These missions involve relief and support in situation based environment, and are as follows:
      - Agricultural aide and monitorship: It will involve spraying of seeds, fertilisers, and

insecticides/pesticides and monitoring of weather changes to detect locust and rodents movement;
- Disaster and relief assistance: It will involve the delivery of relief aid to affected areas and the notification of unaided topography;
- Forestry assistance and vigilance: It is to provide rescue operations and customised guidance about topography and damage. It includes monitoring to detect troubled areas and report their location; and
- Power monitorship: It involves monitoring pipelines and electrical lines, and implementation of recovery and reporting procedures.

- Research: These missions cover topographical exploration in weather and terrain based environment and are as follows:
  - Scientific and geological research aide: The mission involves customised assistance to cover experimentation and analysis.

- Military missions: These are armed missions for an offensive or defensive role and are categorised as strategic and tactical missions. In addition to the operational environment as discussed above, it includes littorals. The missions are as follows:
  - Strategic military missions: These missions are planned and executed at the higher level and have a strategic implication on the operation. A higher threat level is associated with the operational environment. The key features are as follows:
    - Detect electronic emissions: It involves detection of data-loss, data-redundancy and data-surge during transmission and reception, and its reporting;
    - Detect nuclear, biological and chemical emissions: The mission involves usage of multiple nuclear, biological and chemical sensors and equipments to detect and report emissions;
    - Deploy forces and conduct manoeuvres: It involves providing assistance to armed forces by navigating and deploying them into safety zones;
    - Develop intelligence: It involves collection, analysis and documentation of war-time intelligence inputs;
    - Detect, identify and geo-locate communications/non-communication channel: It involves reporting of communication and non-communication channels between airborne vehicles and ground stations by detecting the data-link, classifying it, identifying the source/sink, and finally plotting the source/sink location;
    - Illuminate, range, and designate location: It involves illuminating target area, and updating the control station with its location coordinates;
    - Protect force: It involves enhancing military survivability and supplementing the rescue & recovery; and
    - Weapon delivery assignments: It involves the weapon delivery with minimal ingress and egress time.

  - Tactical military missions: These missions are implemented at field-level. A reduced threat level is associated with the operational environment. The missions comprises of the following:
    - Dispense supply: It involves dispensing of incapacitating agents, logistical supplies, pamphlets and sonobuoys by using ground, meteorological and nuclear, biological, chemical sensors;
    - Command and control: It involves a quick situational assessment through command and control procedures by acquiring, analysing and communicating information to the ground station;
    - Electronic attack and protection: It involves hijacking communication frequency of airborne vehicles and decoying their airflight path by broadcasting deceptive frequency or by jamming the channels. Protection covers re-encryption and closure of the communication frequency;
    - Firepower: It involves engaging targets through detection, classification and tracking;
    - Relay: It involves audio and imagery data relay from airborne

object to ground platform through relay sensors and communication network;
- Imagery and geo location: It involves processing of still & video imagery, and updating the ground station with air-vehicle coordinates by using infrared frequency of a synthetic aperture radar; and
- Target-return data: It involves updating ground control station with target data obtained from multi spectral radar through a surface search algorithm.

The results of the mission analysis are summarised at Table 1.1

Mission Requirement Document

The mission analysis resulted in identification of UAV mission requirements required to develop a generic design architecture based on the operational perspective of present and envisaged UAV technology needs. The identified mission requirements are stated as a "Mission Requirement Statement", comprising of a brief of the probable payload that addresses requirements. The mission requirement statement to develop a generic design process for a VTUAV is listed as follows:

"An unmanned rotary-wing aerial vehicle should be designed that meets reconnaissance & surveillance, agriculture, forest, research and management civil needs in addition to strategic and tactical defence needs in varying terrain, weather, time, situation and threat. The choice of incumbent or customised payload should address mission fulfilment and survivability issues."

The statement is documented in a "Mission Requirement Document" that also considers operational feasibility of rotary wing UAV in several customised environments. This requirement document is an industry standard, explicitly stating fixed mission requirements and serves as base document for the preliminary and detailed design.

Mission profile

Mission profile is a sequential representation of the various phases of the mission from an operational perspective. It provides the flight mode and estimates the time required to fulfill the slated mission requirements as an aggregate of time period for various phases. The flight mode for rotary wing UAV missions comprises of nap-of-earth, low-level, peripheral, high-level, and contour [9, 10]. A generic rotary wing UAV mission profile comprises of following phases:

- Take-off: It is either concealed or open, and includes taxing and take-off time;
- Transit (Source to destination): It involves an outbound transition to destination through a series of way points;
- Ingress: It involves the entrance in threat/non-threat zone;
- Engage: It is execution of the mission;
- Disengage: It is accomplishment/abort of mission;
- Egress: It involves exit from threat/non-threat zone;
- Transit (Destination to source): It involves an inbound transition to base through a series of way points; and
- Landing: It covers both landing and taxing time.

A mission profiles is developed considering the above generic phases to address the operational needs of weapon delivery mission. It provides a series of time periods to evaluate the total mission time and is presented in Figure 1.1.

Summary

The requirement analysis, an integral part of the SEP, investigated required performances or design constraints to which the VTUAV must confirm. It involved appropriate allocation of functional requirements through operational and mission analysis to identify system elements through a system analysis for developing a generic VTUAV design architecture. The framework for requirement analysis is presented in Figure 1.2 and the proposed framework for system analysis is presented in Figure 1.3.

References

1. Sinha, A.K., 2002, AV365-Integrated Aircraft Design, 'Systems Engineering', School of Aerospace, Mechanical and Manufacturing Engineering, RMIT, Australia
2. Sinha, A. K., 1998, 'A System's Approach to the Conceptual Design of Helicopter Multi-role Capabilities', Doctor of Philosophy Thesis, Royal Melbourne Institute of Technology, Melbourne, Australia.
3. Sinha, A.K., Kusumo, R. Scott, M.L. & Yuen, C.Y.Y., 2002, 'A System Approach to the design of multi-mission Airframe for Unmanned Air Vehicles systems,' 17th International UAV Systems Conference, 8-10 April, Bristol, UK.

4. Sinha, A.K., Kusumo, R. Scott, M.L., Bil, C. & Mahondas, P. 2001, 'A System Approach to UAV Systems Issues and Challenges for Technology Development, Test and Validation,' 16th International UAV Systems Conference, 3-5 April, Bristol, UK.
5. VTUAV COE, 'Vertical Take-Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV) Concept of Employment (CoE)', US Naval documentation (Draft G), [Available Online] URL: www.fas.org/irp/program/collect/docs/VTUAVREVGCOE.htm, June 1999, Date Downloaded: 23/05/2005
6. Haskins, S., 2004,'The Latest Challenges, Opportunities and requirements in Unmanned Aerial Vehicles Platforms, Payloads & Missions', Training Course script, 18-19 Nov, London, UK
7. Rathore, A., Sinha, A., 2003, 'A Systems Approach to the Design Architecture of an Unmanned Helicopter', 9th ANZSYS Conference, Systems in Action, Melbourne, Australia.
8. Rathore, A., Sinha, A., 2005, 'Automation of Preliminary Design Process Architecture for a Rotary Wing Unmanned Aerial Vehicle', Eleventh Australian International Aerospace Congress, Melbourne, Australia.
9. Sinha, A. K., 2002, 'Introduction to Preliminary Helicopter Design', Department of Aerospace Engineering, RMIT, Melbourne, pp. 12-59.
10. Brasel, R, 1999, 'Item specification for the vertical takeoff and landing tactical unmanned aerial vehicle (VTUAV)', [Available Online] URL: www.fas.org/irp/program/collect/vtuav.htm, Date Downloaded: 20/07/2003

Table 1.1: Mission requirements derived from mission analysis

Operational needs	Mission clientele	Mission categories	Mission requirements (Sec 3.1.3)	Environment
General	Military & Civil	Generic	• Reconnaissance & surveillance • High altitude scientific research • Fire detection & monitoring	Terrain, weather, time & situation
Special	Civil	Relief & monitoring	• Agricultural aide & monitorship • Disaster & relief assistance • Forestry assistance & vigilance • Power monitorship	Terrain, weather, time & situation
		Research	• Scientific & geological research aide	Terrain & weather
	Military	Strategic	• Dispense supply • Command & control • Electronic attack & protection • Firepower • Relay • Imagery & geo-location • Target-return data	Weather, time & threat
		Tactical	• Detect electronic emissions • Detect nuclear, biological & chemical emissions • Deploy forces & conduct manoeuvres • Develop intelligence • Detect, identify & geo-locate communications/non-communication channel • Illuminate, range & designate location • Protect force • Weapon delivery assignments	Terrain, weather, time, situation & threat

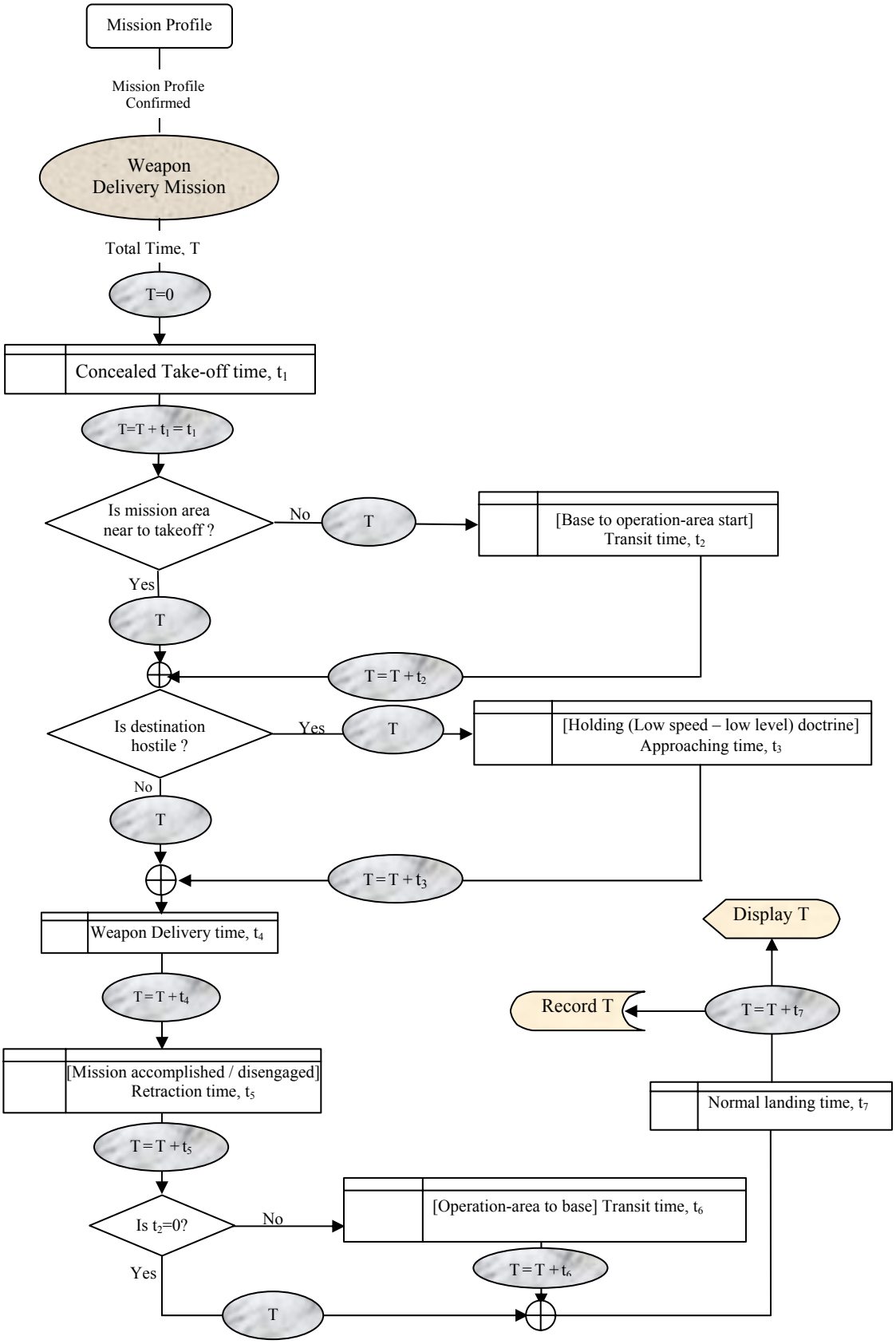

Fig 1.1: Flowchart to calculate mission time of weapon delivery mission

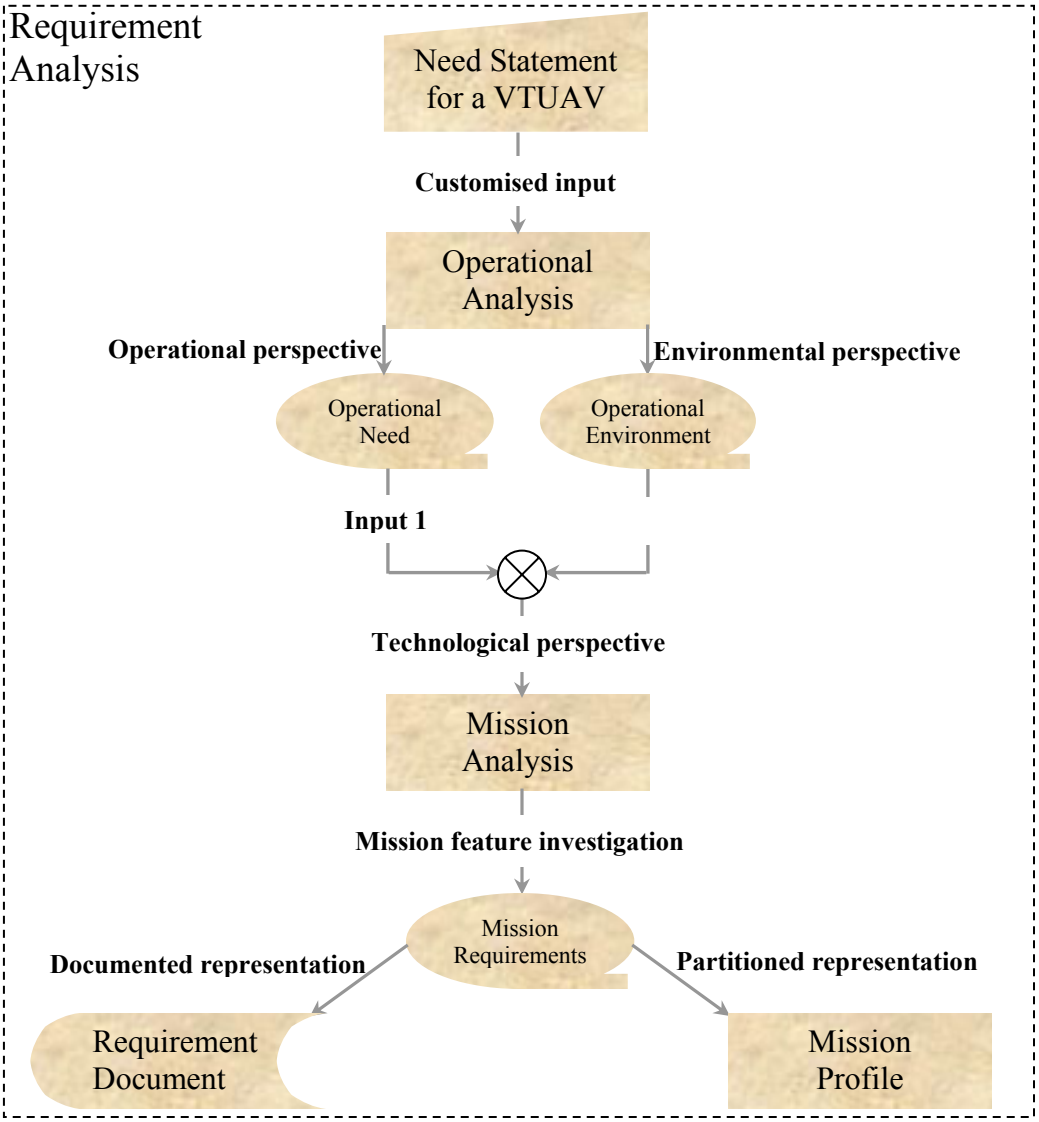

Fig 1.2: Requirement analysis to investigate the required performances and design constraints for a generic VTUAV design

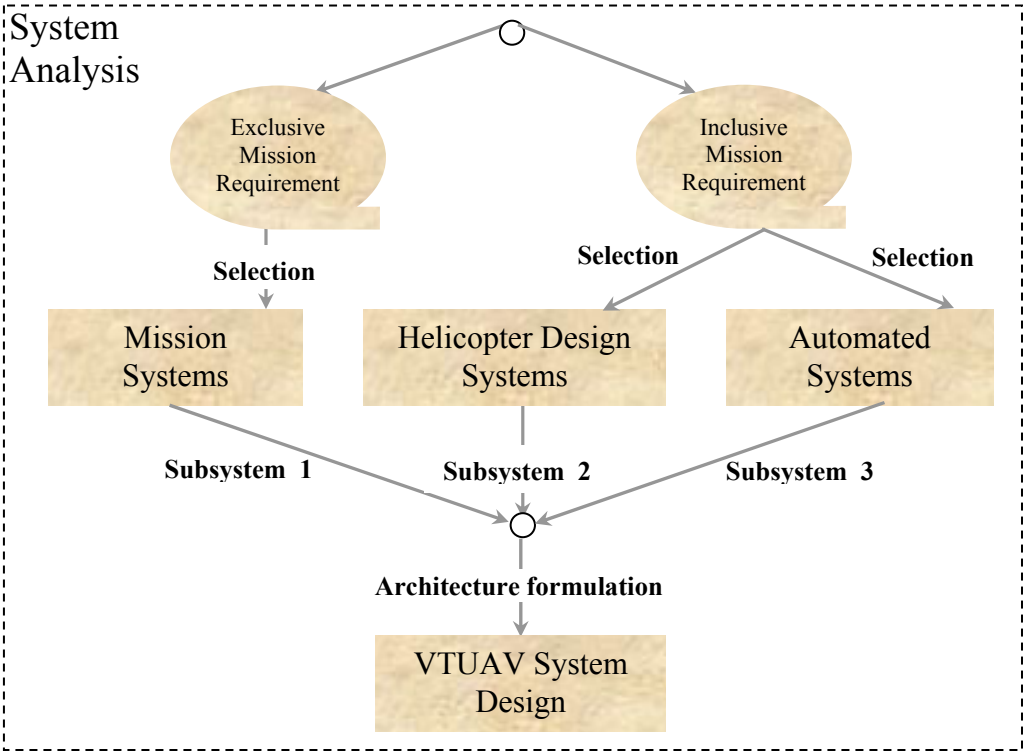

Fig 1.3: System analysis to identify system elements for a generic VTUAV design