DESIGN OF OPTIMUM PAYLOADS TO MEET THE MISSION REQUIREMENTS OF UAV SYSTEMS

Arvind K. Sinha[1], Cees Bil[2] , Murray L. Scott[3] and P. Mohandas[4]

[1,2,3] Sir Lawrence Wackett Centre for Aerospace Design Technology, Department of Aerospace Engineering,
Royal Melbourne Institute of Technology, GPO Box 2476V, Melbourne, Victoria, 3001, Australia
[4]Jawaharlal Nehru University, Secunderabad, India

Abstract

The development of Unmanned Airborne Vehicle (UAV) systems for deployment in a variety of civil, paramilitary and military roles has proved to be a cost-effective option over existing systems. One of the major weak links that exist in the development of UAV systems is the design of an optimum mission payload - a payload that meets the requirements of various System Design Parameters (SDPs).

This paper attempts to apply a systems methodology that considers SDP requirements for optimisation of a UAV system payload. The SDPs considered in this paper for demonstration are operational needs, reliability and maintainability. These disparate design parametric requirements are considered consecutively by an indexing process. A single figure of merit is developed in a format that facilitates the comparison of various UAV mission payloads by considering the degree to which the payload meets the SDP requirements. The comparative study results in the identification of the optimum payload.

1 Introduction

Over the past decade, the development and deployment of UAV systems have not only shown their growing importance in operations but also the unprecedented variety (Herrick, Frost & Sullivan, 1999). A wide variety of UAVs have been tested and deployed to meet the expanding mission requirements. The futuristic mission requirements range from tactical and strategic deployment in a combat and non-combat role for the military, and for surveillance, remote sensing and security for civil applications (Marlow 2000; Herrick 1999).

Hewish in his report on UAVs in the International Defence Review (1998) identified the weak links that exist in the design and development of UAVs. One of the weak links is in the design of payloads that meet the realistic mission expectations. Additionally, recent UAV system designs aim at optimising the payload to meet a range of mission requirements (Bender 2000).

Sinha et al. (1999) adopted a system approach for the formulation of mission payloads for UAV systems. The methodology adopted, identified the payload hardware and its characteristics (attributes) by the development of a "system hierarchy". A mathematical model was derived to evaluate the degree to which a payload would meet the mission expectations. This model derived the inputs from "mission contribution matrices".

"Operational needs" was the only System Design Parameter (SDP) considered by Sinha et al. (1999) in the design of UAV mission payload. From a systems perspective, for design optimisation, all SDP requirements are to be considered (Sinha et al. 1996a). The degree to which the design under consideration satisfies the SDP requirements is to be integrated to identify the optimum solution.

This paper attempts to consider additional SDP requirements and drawing up a Figure-of-

Merit (F-of-M) for integration of SDP requirements to identify the optimum payload.

2 System design parameters

When a systems approach is adopted, the aim is to design a system that is operationally acceptable, technologically feasible, financially viable and logistically supportable (Sinha et al. 1996a). Thus, holistically the major SDRs that need consideration are operational needs, performance, reliability, maintainability and cost.

By designing payloads from available equipment packages in the market, the technological feasibility requirement is addressed. Flight performance can only be considered through a case study on a particular airframe. Reliability, maintainability and cost parametric requirements could be evaluated through established methods. Sinha et al. (1996b, 1998) demonstrated a methodology by application of systems approach to evaluate reliability and maintainability of multi-mission equipment packages for helicopters.

The Tactical Sub-System (TSS) developed by Sinha et al. (1999) and the Tactical UAV development discussed by Hewish (2000) are considered in this paper for the design of an optimum payload for a Tactical UAV.

3 Tactical subsystem

The tactical sub-system designed by Sinha et al. (1999) requires a re-study due to the combat role that the tactical UAV is expected to undertake in future battles. The re-designed TSS hierarchy with four levels (Level I to IV) and the partial mission contribution matrix of component and component relationships are presented in Figure 1 and Figure 2 respectively.

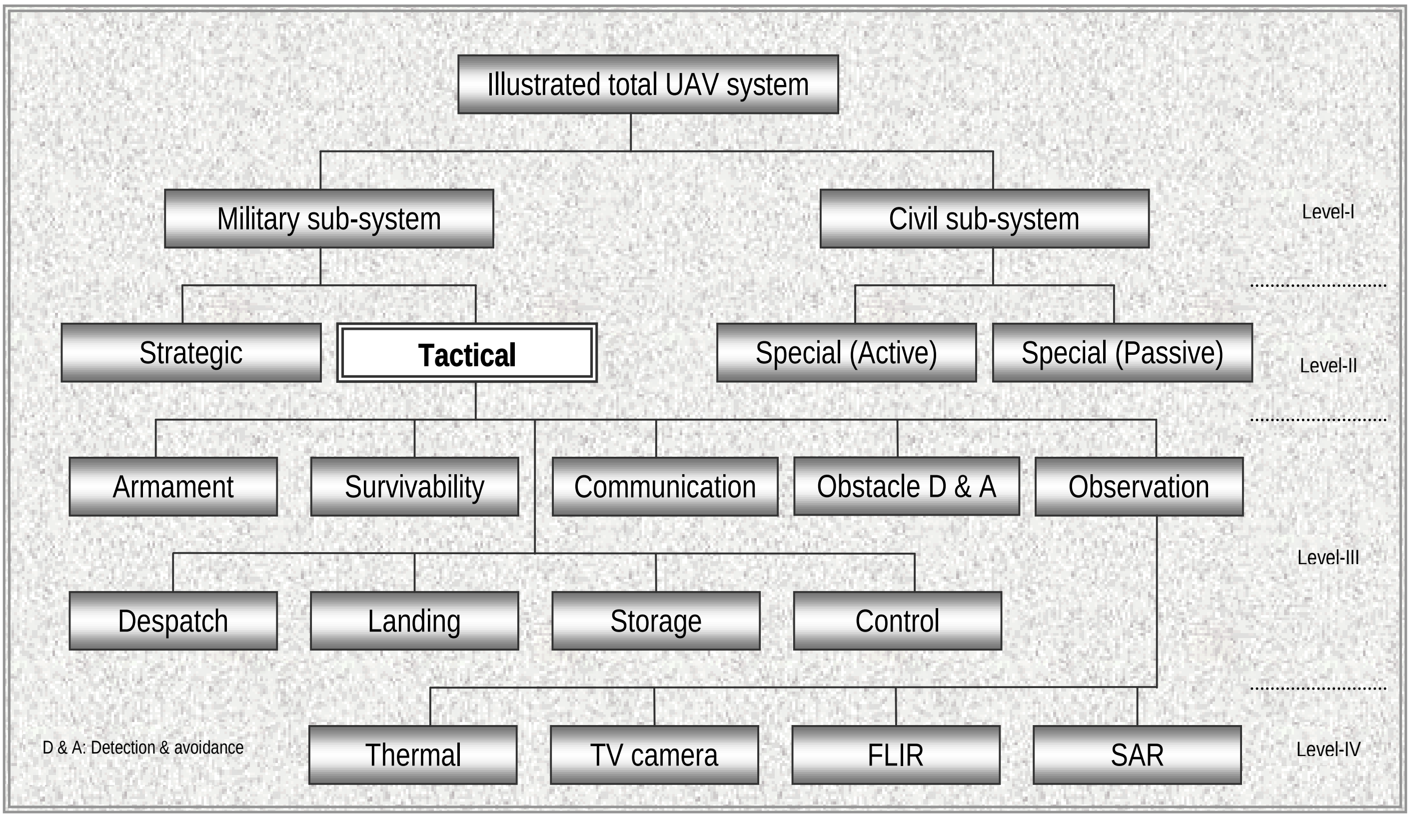

Figure 1 Partial system hierarchy (Tactical sub-system)

System components		Mission contributions								
Offensive & defensive armament	C-1	0	3	0	0	0	0	0	5	5
Survivability suite	C-2	3	0	5	0	2	3	0	0	0
Observation	C-3	0	5	0	3	1	5	2	5	5
Navigation	C-4	0	0	1	0	0	3	3	4	0
Tactical communication	C-5	0	2	1	0	0	0	3	4	4
Obstacle detection & avoidance	C-6	0	3	5	3	0	0	0	2	0
Despatch	C-7	0	0	2	3	3	0	0	3	0
Command and control	C-8	5	0	5	4	4	2	3	0	2
Expendable storage	C-9	5	0	5	0	4	0	0	2	0
		C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9
• Component and component		13	13	24	13	14	13	11	25	16
• Component and attribute		28	34	38	26	22	13	10	42	19
• Total mission contribution		41	47	62	39	36	26	21	67	35
NMCV		**10.9**	**12.6**	**16.6**	**10.4**	**9.6**	**6.9**	**5.6**	**17.9**	**9.5**

Figure 2 Partial mission contribution matrix of level 4 : Component and component (Tactical sub-system)

To meet the combat role requirements, the hierarchy identified additional payload hardware components and their attributes. The mission contribution matrices developed by the study of inter and intra functional relationships between the components and attributes re-quantified the relative contribution of each component and attribute to the mission.

The total mission contribution by a component/ attribute is normalised. A Normalised Mission Contribution Value (NMCV) is then assigned to the components and attributes for calculation of the operational needs met by a payload.

Based on the NMCVs, the Decision Support System (DSS) was re-derived. The DSS presents the components and their attributes in the order of importance in mission contribution. The DSS (Figure 3) aids in the formulation of the mission payloads in a manner that the operational needs are maximised.

4 Payloads

Five payloads (PL-1 to PL-5) were designed with the aid of the DSS by systematically de-grading the mission contribution of components/ attributes. For each of the payload the degree to which it meets the SDP requirements (Operational needs, reliability and maintainability) were evaluated by application of the systems methodology developed by Sinha et al. (1996b, 1998, 1999).

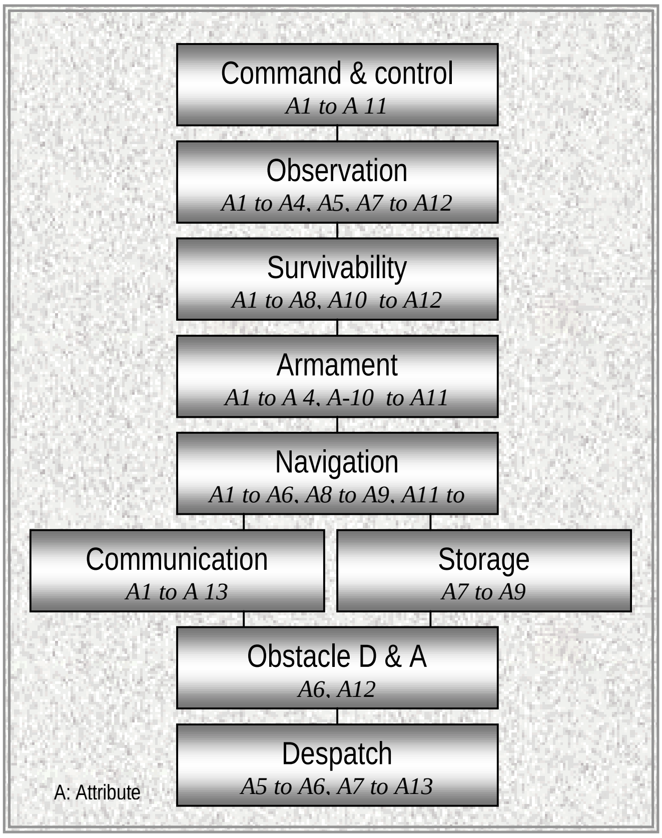

Figure 3 Decision support system (Tactical subsystem)

The operational needs met by the payloads are evaluated by summation of the NMCVs at each level of the system hierarchy. Reliability and maintainability of the hardware components of the payload are evaluated from the manufacturers supplied 'mean time between failure' and 'mean time to repair' values respectively. A ‘system reliability block diagram’ and a ‘system maintainability table’ were designed for evaluating the reliability and maintainability of the payloads. The evaluated degrees of SDP requirements met by the payloads, PL-1 to PL-5 are presented in Table 1.

An indexing process integrates the evaluated degrees of SDP requirements met by the payloads. System Design Parameter Indices (SDPIs) are calculated as a ratio of the evaluated value and the ideal value, making the unit of measure dimensionless, and hence comparable. The evaluated SDPIs for payloads, PL-1 to PL-5, are presented in Table 1.

4.1 Optimum payload

The F-of-M (Figure 4) is developed from the SDPIs of the payloads. The F-of-M provides an insight into the variation pattern of the SDP requirements met by the payloads. To identify the optimum payload, the acceptable limits (design parametric constraints) of the SDP requirements are superimposed on the F-of-M. This results in a design window within which lies the optimal payload.

Table 1 System design parameter indices

Parameters		Evaluation	PL-1	PL-2	PL- 3	PL- 4	PL- 5
	Ideal	$ON_{PL(i)}$	*100*	*100*	*100*	*100*	*100*
Operational needs (ON)	Value	$ON_{PL(x)}$	*100*	*94.4*	*87.5*	*78.0*	*69.5*
	Index	$OI_X = ON_{PL(x)} / ON_{PL(i)}$	**1**	**0.94**	**0.88**	**0.78**	**0.70**
	Ideal	$R_{PL(i)}$	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*
Reliability (R)	Value	$R_{PL(x)}$	*0.73*	*0.77*	*0.78*	*0.84*	*0.88*
	Index	$RI_X = R_{PL(x)} / R_{PL(i)}$	**0.73**	**0.75**	**0.78**	**0.84**	**0.88**
	Ideal	$M_{PL(i)}$	*0*	*0*	*0*	*0*	*0*
Maintainability (M)	Value	$M_{PL(x)}$	*0.27*	*0.26*	*0.26*	*0.23*	*0.20*
	Index	$MI_X = \lvert M_{PL(i)} - M_{PL(x)} \rvert$	**0.27**	**0.26**	**0.26**	**0.23**	**0.20**

Legend
I: Index PL(i): Ideal payload PL(x): Payload under consideration

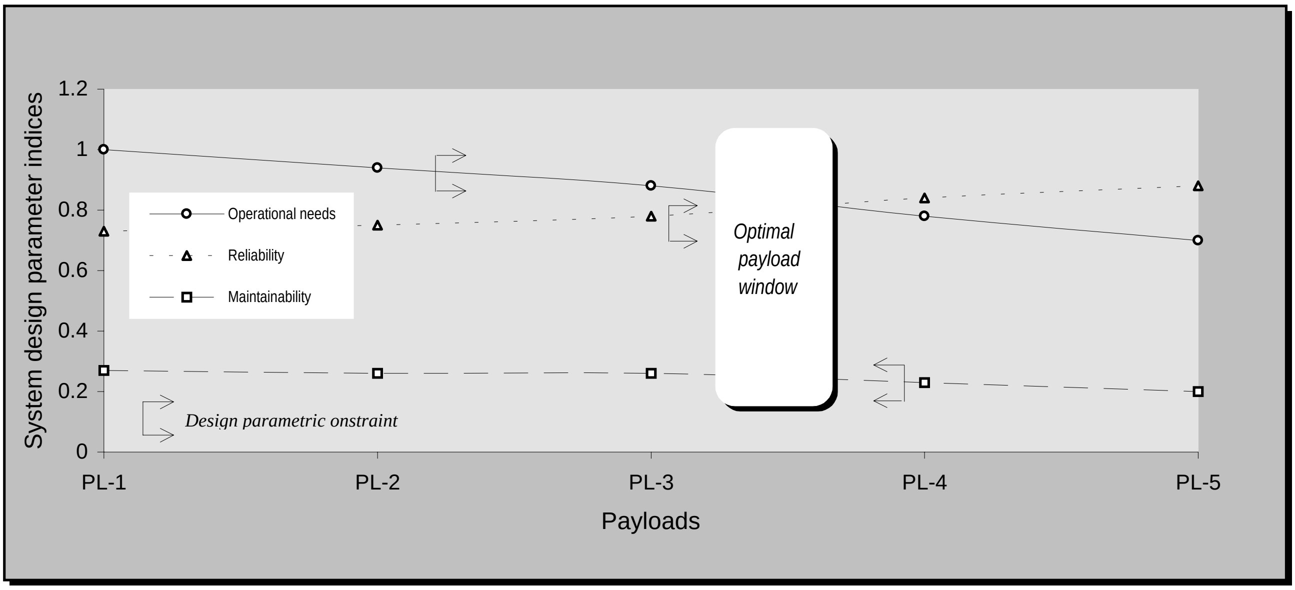

Figure 4 Figure of merit for identifying the optimum payload

5 Discussion and concluding remarks

5.1 Discussion

The DSS identifies the Command and Control system on board as the most important system. It contributes 17% of inputs required for mission accomplishment. The Observation system that houses the sensors for imagery intelligence is next in mission contribution. These two are in place as the major UAV missions are for surveillance and reconnaissance and the success of UAV missions totally relies on command and control.

As tactical UAVs would operate in a combat zone, protection against threat of adversaries needs to be in-built. The result of the mission contribution analysis has rightly graded the Survivability and Armament systems as next on the list for consideration in the design of the payload.

Obstacle detection and avoidance, and the Despatch system's contribution are the least in mission accomplishment. This supports the fact that UAV deployment in launch of smoke canisters has been on a lower scale and Nap-of-Earth flight of UAV is presently remote.

The figure of merit presents the relative degree of SDP requirements met by the payloads PL-1 to PL-5. The operational needs met by PL-1 is maximum (100%) and it reduces to 70%, met by PL-5. As the operational needs met by the payload reduces, the reliability increases and maintainability reduces. From a logistic support perspective, it is acceptable, but not operationally, as the mission requirements would be compromised. Hence, by laying the limit of acceptance (constraints) for each SDP requirement, the optimisation of the payload was achieved. A payload if designed between PL-3 and PL-4 would meet all the SDP requirements of operational needs, reliability and maintainability and could be identified as an optimum payload.

5.2 Concluding remarks

The optimum payload identified in this paper considers only three SDP requirements, operational needs, reliability and maintainability. The optimum payload design requires consideration of system performance and cost requirements. An example airframe is required for mission performance evaluation of the payloads PL-1 to PL-5. The SDP indices of performance and cost must be evaluated separately and integrated on the figure of merit presented in Figure 4. It would re-generate a new optimum payload design window. The optimum payload could then be attempted for design.

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