VOL. 9, NO. 3, MARCH 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# MARKOV BASED EXPLORATION FOR AIRCRAFT DESIGN TIME COMPRESSION

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## ABSTRACT

The design of Aircraft and especially the fighter Aircraft is increasingly getting complex. Added to the complexities of the design and need to integrate several disciplines, there is an added challenge of working with technologies that are still in drawing boards to be incorporated in future design. Needless to add, validation and testing of entire system / subsystem is a pain point. Hence there is a clear need to design the aircraft in such a manner to accommodate for futuristic technologies and compress the design cycle times. On an average, design and development of a Military aircraft either for developed countries or developing countries requires a minimum of 13 years from the launch of project to the first flight. As the years get passed on new technologies and advancement also develops and it will become difficult to identify and incorporate to the ongoing projects. A novel approach of using Markov process for achieving these objectives is explored. Markov based approach as a stochastic approach normally used to predict future states on the basis they have no link to the past is explored. A step by step approach by taking a typical design life cycle process of a particular component/assembly of aircraft is discussed. In this, design is split in to sequential stages, based on our prior design experience a probability is assigned to all foreseeable possibilities, and then that is converted to transition probability. Using a simple concept that any probability less than 1.0 leads to extended design life cycle, suitable cost and time factors.

**Keywords: f**ighter aircraft, life cycle time, Markov, probability.

## INTRODUCTION

Aircraft system design and analysis is a tricky process due to the various design options, design complexities and interdependency factors involved in each system. As Aircraft system design advances concurrent with progresses in technology the corresponding complexity also increases. With increased complexity, it is more difficult to analyze and predict the system health.

Design and Development of a Military Aircraft either for developed or developing countries requires a minimum of 13 years from the launch of project to the first flight.

Figure-1 shows lead time required from launch of project to first flight of various major military aircraft of the world. The long lead time for realization of military aircraft is mainly due to conflicting requirements and technologies involved in the design process and also compliance with the weight, combat requirement and stringent military specifications to get flight clearance from respective aviation bodies. Military Aircraft is the only engineered product, wherein the design envisages yet to be developed and proven.

For success of aerospace industry the products must be affordable, conform to the highest quality standards, perform atleast as envisioned and to be produced on time. In addition, the aerospace industry must be flexible to support not only system upgrades but flexible in terms of volume and product variety [1].

There are significant challenges associated with design for performance and manufacturability of aircraft structures, in which a formidable task is the development and implementation of methodologies that can accurately and efficiently address manufacturability and cost requirements in the design process. In addition there is a need for efficient optimization techniques that can provide effective design solutions to multicriteria problems with diverse sets of constraints and objectives. [2].

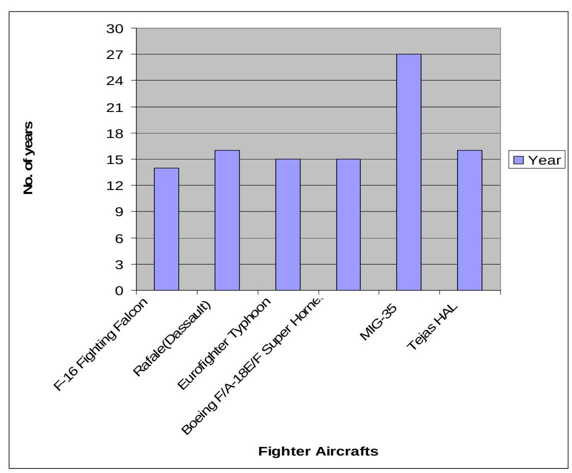


**Figure-1.** Lead Time for First Flight.

In design of large systems like aerospace and defense it is very difficult to prevent major delays and short falls on almost all programs - a theory has been developed that these overruns and setbacks are not an unfortunate vulnerability but are instead a natural outcome of complex product development performed in accordance with system engineering military standards.

Decades of cutting edge methods, process and tools have been injected in to the systems engineering process but to no avail. This includes a great deal of research and tool development in multidisciplinary optimization. Despite major innovations enabled by desktop computing and networks, bottom line performance in the large class of engineering program is no better [3].

The most important benefit perceived from an individual point of view in aerospace industry is that PLM helps a reduction in time spent for retrieving information, as well as an increase in time spent on individual technical work. [4].

## MARKOV CHAIN AND ITS BACKGROUND

In 1907, A.A Markov began the study of an important new type of chance process. In this process, the outcome of a given experiment can affect the outcome of the next experiment. This type of process is called Markov chain. Modern probability theory studies chance processes for which the knowledge of previous outcomes influences predictions for future experiments. In principle, when we observe a sequence of chance experiments, all of the post outcomes could influence our predictions for the next experiments.

R.A Howard provides with a pictorial description of a Markov Chain as a frog jumping on a set of lily pads, the frog starts on one of the pads and then jumps from lily pad to lily pad with appropriate transition matrix. [5].

The Markov chain theory is widely applied to predict a dynamic random system. A Markov chain describes the states as system at successive times. At these times the system may have changed from the state it was in the moment before to another or remained in the same state. The changes of state are called transitions. The Markov property means that the conditional probability distribution of the state in the future, given the state of the process currently and in the past, depends only on its current state and not on its state in the past. A n-step Markov chain is composed of a set of n-sate and one set of transition probability. There is only one state at one moment, and any further changes in the system can be determined by the transition probability in each state at different moments. The transition probability of each state represents the level of effects incorporating every random factor. Therefore the Markov chain is suitable for forecasting random series.

From literature survey it is observed that Markov chain is mainly used in economics and decision solutions. Some of the aerospace applications wherein Markov process in explored is briefed as below.

A method for quantifying uncertainty in conceptual level design via computationally efficient probabilistic method is described and as an example the method is applied to estimating the propellant mass required by a spacecraft to perform attitude control. [6].

One way to develop hazard alerting system is based on probabilistic models is by using a threshold based approach and another way to develop such a system is to model the system as a Markov decision process [7].

Introduction to an integrated approach for the early stage multi state design and analysis of an aircraft requiring robust performance of nominal system states is accomplished using Markov chain analysis within the design group to stochastically model state transition. [8].

From the literature surveys it is obvious that the Markov process is used in probabilistic modeling in many field including aerospace wherein it is applied for performance improvements, robustness etc but the exploration of this process at design stage for reducing the cycle time is rarely used in aircraft field, In this paper authors with experience in the field of design and building military aircrafts have attempted to explore the Markov process for time compression at design stage with a typical case study and its application.

## APPLICATIONS AND APPROACH OF MARKOV CHAIN AT DESIGN STAGE

Markov chain can be described as follows, if we have set of states. $S=\{s_1, s_{2,} ........s_3\}$ The process starts in one of these states and moves successively from one state to another. Each move is called as step. If the chain is currently ion state $s_i$, then it moves to $s_j$ at the next step with a probability denoted by $P_{ij}$, and this probability depend upon which states the chain was in before the current state.

The probabilities $P_{ij}$ are called transition probabilities. The process can remain in the state it is in and this occurs with probability $P_{ii}$. An initial probability distribution defined on S, specifies the starting state, usually this is done by specifying a particular state as the starting point.

On the above procedure Markov chain can be applied to design stage as given below:

i) A typical design process of a Aircraft structural component or a standard product can be summarized as shown in Figure-2.

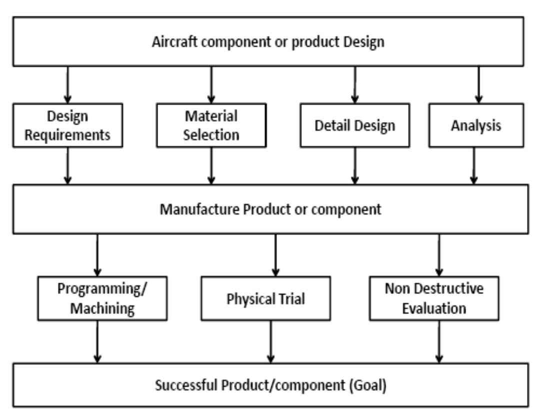


**Figure-2.** Aircraft structural part design.

VOL. 9, NO. 3, MARCH 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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ii) The above process of realizing final product can be reduced to a 3 stage process as shown in Figure-3.

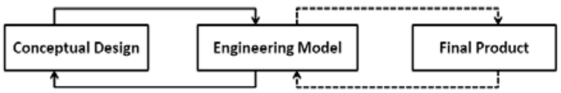
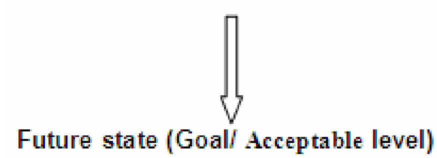



**Figure-3.** Reduced design stages.

iii) For any activity such as design or manufacturing or testing there are two states that is current state and future (desired) state.

**Deterministic current states (Resource available)**




iv) The current states are assigned with a Critical Success Factors (CSF) to achieve the goal and this will be denoted by S. These CSF data are those which will be derived from the general engineering design concepts required to design a typical aircraft components or reference from other past design knowledge.
This can be represented as

$$S^{(0)} = [p_1^{(0)}\ p_2^{(0)} \ldots\ldots\ldots p_m^{(0)}] \quad (1)$$

Where $p_1^{(0)}$ denotes the probability that $p_1$ takes the value $s_1$ and so on.

v) The above CSF are converted in to probability mix, that is as we discussed in the above chapters for the complex and interdependent design process such as aircrafts there is always variations occurring in terms of specifications, changes in technology, expertise etc hence we cannot expect the initial status to be constant and hence probabilities of variations are assigned in terms of transition matrix and it is denoted by P as shown in equation.

$$P = \begin{bmatrix} p_{11} & p_{12} & - & - & p_{1m} \\ p_{21} & p_{22} & - & - & p_{2m} \\ - & - & - & - & - \\ - & - & - & - & - \\ p_{m1} & p_{m2} & - & - & p_{mm} \end{bmatrix} \quad (2)$$

Due to the changes in probabilities the next states are calculated as below:

$S_1 = S^{(0)} \times P$, $S_2 = S_1 \times P^2$, $S_3 = S_2 \times P^3$ and so on.

vi) The above chain is continued till the desired success (goal) is reached, the desired success or goal or final probability mix will be defined by the expertise in the field or from past study of similar design cycles.

vii) The number of stages required to achieve the desired goal will determine the lead time of any design cycle or manufacturing cycle etc.

## TYPICAL CASE STUDY TO ILLUSTRARE MARKOV CHAIN AT DESIGN STAGE

Let us consider designing of an Actuator for aeronautical application, design process for this assembly are as shown in Figure-4.

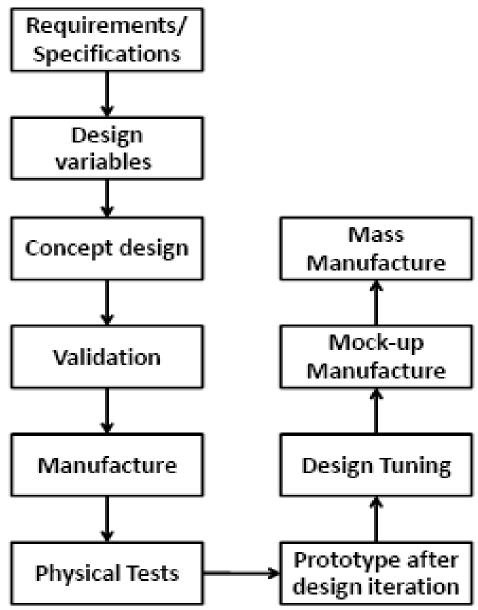



**Figure-4.** The design process for actuator.

Most of the projects or design process as we explained in the section 3 depends on the available resource and future goal. In this case future goal will be acceptable Actuator functionality and the determinants of design stage can be split in to 4 states such as Requirements/Specifications(R) Knowledge (K), Past Experience (E) and Design Tools (T).

In this problem the requirement is, can we achieve the future state and if it is yes in what time?

If we consider the present resources (Critical success factors) as for Requirements/Specifications 10%, Knowledge 50%, past experience 30% and Design Tools as 10% to achieve the goal and apply to Equation (1) the initial state can be written as below

$$S^{(0)} = [R^{(0)}\ K^{(0)}\ E^{(0)}\ T^{(0)}]$$

By incorporating the determinants as per above the equation can be written as

$$S^{(0)} = [0.1\ 0.5\ \ 0.3\ \ 0.1]$$

The probability mix from prior evaluation and previous experience are assumed as presently expected future status reduced to probability Figures and incorporated in Equation (2) and given as below:

$$P = \begin{bmatrix} 0.15 & 0.40 & 0.30 & 0.15 \\ 0.10 & 0.45 & 0.35 & 0.10 \\ 0.20 & 0.50 & 0.20 & 0.10 \\ 0.25 & 0.25 & 0.35 & 0.15 \end{bmatrix}$$

$$S_1 = S^{(0)} \times P$$

That is

$$S_1 = [0.1 \;\; 0.5 \;\; 0.3 \;\; 0.1] \times \begin{bmatrix} 0.15 & 0.40 & 0.30 & 0.15 \\ 0.10 & 0.45 & 0.35 & 0.10 \\ 0.20 & 0.50 & 0.20 & 0.10 \\ 0.25 & 0.25 & 0.35 & 0.15 \end{bmatrix}$$

Solving above we will get State 1 as below

$$S_1 = [0.15 \;\; 0.44 \;\; 0.3 \;\; 0.11]$$

$S_2 = S_1 \times P^2$ After applying above and solving we get

$$S2 = [0.1544 \;\; 0.4345 \; 0.2976 \;\; 0.1133]$$

Similarly

$$S3 = [0.1544 \;\; 0.4344 \; 0.2976 \;\; 0.1133]$$
$$S4 = [0.1544 \;\; 0.4344 \; 0.2976 \;\; 0.1133]$$

From the above calculations it is observed that the desired state for the resource requirement to achieve the goal is converging and approximately constant after 4th iteration, this implies that in order to have future goal achieved it is essential to have 15.44% of specifications, 43.44% of knowledge, 29.76% of Past experience and 11.33% of design tools.

If we consider iterations (state) as one year time then the desired goal or design of the actuator will be completed after 4 years lead time. This will give a fairly accurate idea for management to take necessary steps to either reduce the delays or to plan the final target of new projects.

## CONCLUSIONS

a) A novel way which is goal based approach has been attempted and illustrated.
b) An attempt has been made to view the problem of complex design projects through Markov chain approach.
c) Bringing of the entire mass data into an useful and compact information has been attempted
d) With the above approach there is always a possibility that root cause analysis can be done in order to assess the cause of delays in any activity such as design, manufacturing, testing etc by going at micro level of each sub states
e) As computer based matrix calculations are available, this process offers a simplistic tool of handling myriad variables and associated stage wise risks.

## LIMITATIONS OF THE WORK

The above process critically depends on defining and arriving at Critical Success Factors (CSF) and hence deducing the probability Mix.

The assigned probability Figures in the absence of historical data can be arbitrary or based on best judgment.

Markov process like any other statistical technique depends on making reasonable assumptions which are aligned with reality or else it would lead to erroneous results.

## SCOPE FOR FUTURE WORK

This work although novel, gives only a frame work, more work needs to be done in capturing delays due to technological obsolescence in to transition matrix.

Same concept can be extended to decision tree model and stage wise Markov chain models can be built.

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