CONCEPTUAL DESIGN AND PROPOSED DEVELOPMENT OF THE GAP-4 MULTI-PURPOSE SMALL UTILITY HELICOPTER

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Abstract

Based on an evaluation of the world's potential market for small helicopters ranging from two to six seats Executive AeroSystems Inc. EAI and Georgia Institute of Technology (GIT) in the USA as well as Istanbul Technical University (ITU) and ITU-KOSGEB Technology Development Center company Anka Helicopter Ltd. (AHL) in Turkey have initiated a conceptual design and feasibility study for a piston engine powered four seat helicopter named "GAP-4" with superior hot day/high altitude performance characteristics. It will utilize an advanced rotor system with aerodynamically optimized airfoil sections, composite blades with high structural integrity and will require only minimal maintenance due to emphasis on simplicity, minimization of parts count and on-condition service and repair. This paper presents the GAP-4 conceptual design and discuss a planned university /industry/government collaborative development program in both Turkey and the United States that will complete the design of the GAP-4 Helicopter and demonstrate its capabilities for manufacturing in Turkey. A major objective of this program will be to foster the development of a helicopter industry in the Republic of Turkey.

Introduction

Executive AeroSystems Inc. (EAI) with the support of Istanbul Technical University (ITU) and Anka Helicopter Ltd. (AHI) in Turkey as well as the Georgia Institute of Technology (GIT) and Dynamic Engineering Inc. (DEI) in the USA have prepaired a proposal to be submitted to the government of Turkey. This proposal describes a program to involve and train Turkish nationals in the design, development, certification of a small, multi-purpose, high performance four to five seat helicopter. The proposed program will facilitate first of all the establishment of a self reliant indigenous advanced technology aircraft design, development and manufacturing capability within Turkey. Second, the helicopter to be developed by the proposed program will satisfy a critical need for an inexpensive helicopter that can operate throughout Turkey and neighboring countries in hot-day and high-altitude conditions at design gross weight. Such a helicopter will have a profound impact in helping Turkey develop the Southeastern Anatolian region. For this reason and the fact that it will be basically a four seat passenger machine, it is named "GAP-4" and GAP is the Turkish abbreviation for Southeastern Anatolian Project. A three-dimensional computer modeling of GAP-4 is seen in Figure 1. The commercial helicopter selected for development in the proposed program is the result of extensive market research which has identified Turkey's need for a new small and inexpensive helicopter that is capable of filling at least the following missions:

**Personal transportation*
**Aerial observation and surveillance*
**Agricultural applications*
**Basic Emergency Medical Service (EMS)*

at 90% of Turkey's hot-day high altitude conditions as depicted by Fig. 2 where density altitude variatons in August have been illustrated. As seen in Fig. 2 drensity ratios ρ/ρ_o between 0.75 and 0.85 are quite common conditions in Eastern and Souteastern part of Turkey.

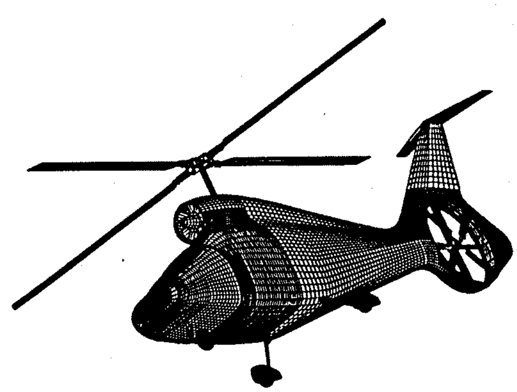


FIGURE 1- Three Dimesional View of GAP-4 Helicopter.

The superior performance capabilities of the proposed GAP-4 helicopter, made possible by use of carefully selected advanced technologies, will enable it to fill the above identified missions. Additionally, the design approach being used should insure an acquisition and direct operating cost at least 25% its nearest competitor.
In addition to satisfying Turkey's small utilitiy helicopter needs, the proposed commercial helicopter will be unique contender in the world's potential market because of its superior performance, operational utility and low cost. Market research has indicated that approximately 3,000 new small four to five seat helicopters with low

acquisition and direct operational costs will be needed world wide in the next 10 to 15 years. If the proposed GAP-4 helicopter can be developed, certified and put in serial production within the next four to five years, Turkey should be able to capture at least 40 % of this world market and realize a significant improvement in its aviation industry.

Development of the proposed helicopter will be accomplished by EAI, operating as one of a kind world class Integrated Product/Process Design (IPPD) Bureau. IPPD is a management methodology that incorporates a systematic approach to the early integration and concurrent application of all the disciplines that play a part throughout a system's life cycle. IPPD embodies the simultaneous application of both system and quality engineering methods throughout an iterative design process. IPPD is having profound impact on producing affordable products in many segments of the commercial sector.

The Turkish nationals assigned to work with EAI in developing the proposed helicopter will be able to master the complete IPPD management methodology as well as the many technical disciplines involved in the execution of such an advanced development program. Upon completion of the proposed program, these nationals will be equipped with the knowledge and expertise to establish an advanced world class aircraft industry in Turkey that can compete successfully in the world market.

EAI and the US based organizations that will support it in development of the proposed GAP-4 helicopter are leaders in the development of rotorcraft technology, possess an abundance of expertise and experience, and are already working together and with the Government of Turkey in developing helicopter engineers, a needed resource for the development of a Turkish helicopter industry. Technology transfer is also proposed through the use of existing aircraft assembly facilities in Turkey, such as Tusas Aircraft Industries (TAI). By leveraging these existing relationships and capabilities of the various organizations that will be involved in the proposed development program, Turkey can best achieve its prime objective- the establishment of its own helicopter industry.

A three phase program is envisioned for the GAP4 Program:

- <u>Phase I:</u> Preliminary/ Detail Design and Prototype Development and Demonstration (2.5 years)
- <u>Phase II:</u> Production Prototyping and Certification Completion (2.0 years)
- <u>Phase III:</u> Full Rate Production

EAI will provide overall program management, configuration and design control, and system integration for the GAP-4 Program during Phase I to insure that an IPPD approach is followed to accomplish all the program objectives in a timely and cost effective manner. A feature based design approach will be used to provide a seamless transition from Computer Aided Design Manufacturing (CAM). GIT through its Center of Excellence in Rotorcraft Technology (CERT) and its Aerospace Systems Design Laboratory (ASDL), would lead the aerodynamics and structural analysis effort. Both off-line analysis as well as real time man-in-the-loop flight simulation in the GIT Flight Simulation Laboratory (FLIGHT SIM) are proposed both for risk reduction and support of the IPPD effort. GIT would be closely assisted by ITU in this effort and would involve the Turkish engineers at GIT as part of the Sikorsky S-70 Education and Training Offset Program. Wind tunnel models, mockups and a rotor test stand would be built during Phase I for testing both at GIT and in Turkey.

Except for vendor supplied equipment such as the engine, main rotor transmission, hub and blades as well as the tail rotor gear box and blades, design of the GAP-4 helicopter will be the responsibility of EAI and conducted in its facilities using highly skilled and seasoned professionals who have demonstrated competence on many previous aircraft programs. DEI, which has been proven supplier to the national and international aerospace community since 1972, will be responsible for the design, fabrication and test of the main rotor hub and blades as well as the tail rotor blades.

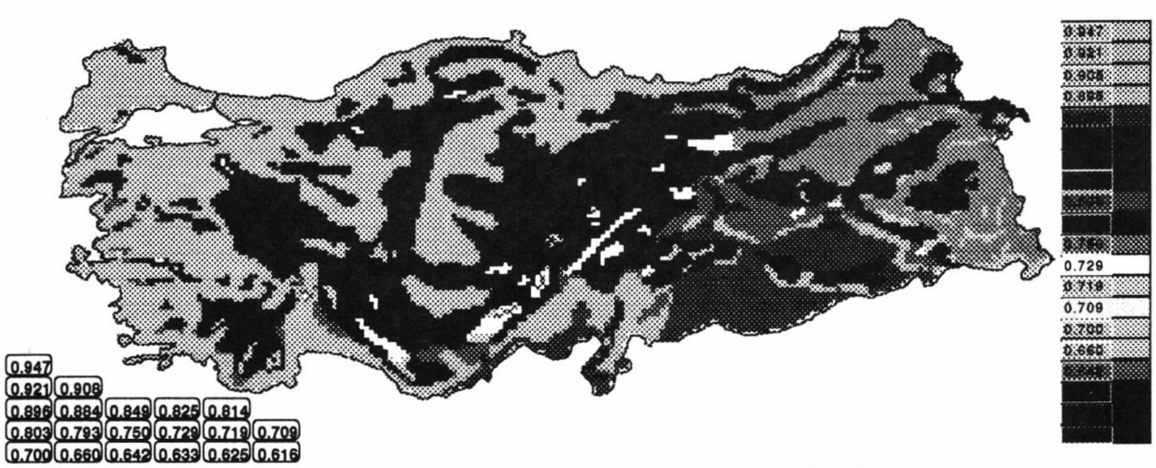


FIGURE 2- Density altitude variation of Turkey

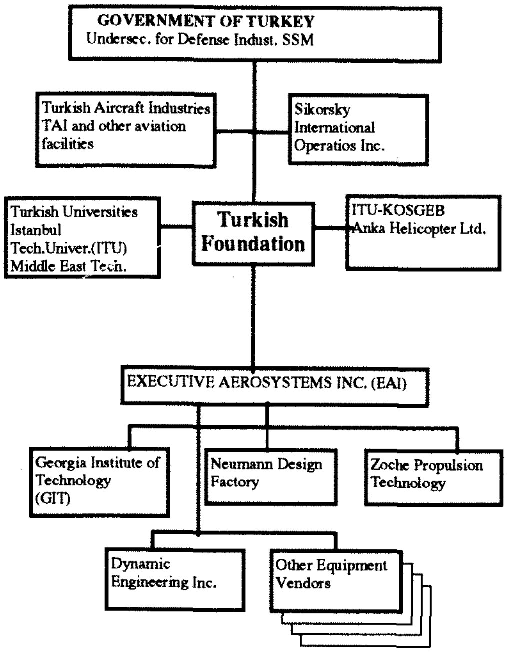


FIGURE 3- GAP-4 Program Structure.

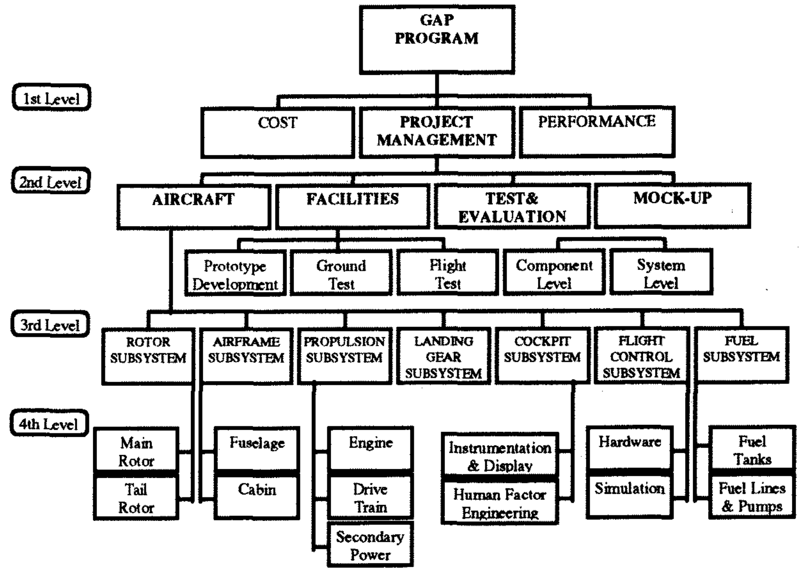


FIGURE 4- GAP-4 Program Work Breakdown

The main rotor transmission and tail rotor gearbox will be subcontracted to one of several companies which have demonstrated over many years the capability to design, develop and manufacture highly successful hardware.

The proposed organizational and funding flow for Phase I is illustrated in Figure 3. It is envisioned that a Turkish Foundation would be set up to coordinate the GAP-4 Program, insure the proper communication between the participating Turkish organizations and EAI, and provide the funding for the proposed program. Direct funding would flow from the Turkish Foundation to ITU and AHL in Turkey as well as to EAI in the USA. EAI would provide appropriate documentation to the Turkish Foundation for the funds required to support the design and development effort.

The GAP-4 helicopter development program shown in Figure 4 offers Turkey a very cost effective way to acquire both a modern helicopter needed to meet its in country needs and the expertise to develop and establish a modern Turkish helicopter industry. Even so, the cost can be made even more cost effective by using off-set funds available from Sikorsky's sale of S-70 helicopters to Turkey. It would be appropriate to use these off-set funds for the proposed program since some of these funds are already being used to educate and tı in Turkish engineers at GIT and Sikorsky Aircraft.

The Production Prototyping ar d Certification Completion, which comprise Phase II, would be led by a Turkish company formed specifically to manufacture the GAP-4 helicopter in Turkey. To insure successful technology transition from Phase I to Phase II and to insure an IPPD approach is used successfully all the way through production, EAI would need to be included as part of the Turkish Company.

Program Objectives

Project Program Overview

The initial phase of the proposed program will involve seven major tasks which are summarized and listed below:

- Modify the conceptual baseline design for the proposed four seat helicopter based on feedback from the Government of Turkey
- Provide Preliminary Design/ Detail Design Configuration Control (CAD thru CAM & Specifications)
- Complete the preliminary design by providing the following:
  - *Conduct product/ process design tradeoffs down to the subsystem level*
  - *Preliminary Design Analysis*
  - *Performance*
  - *Stability &Control*
  - *Dynamics/ Aeroelasticity*
  - *Propulsion/ Drivetrain*
  - *Flight Controls/ Simulation*
  - *Human Factors/ Cockpit Layout*
  - *Static Wind Tunnel Test*
  - *Mockups (CAD validation, Cockpit and subsystem layout, Maintenance Access)*
  - *Conduct Preliminary Design Review (PDR)*

- Complete detail engineering design by providing the following:
  - *Conduct product/ process design tradeoffs down to the component level*
  - *Complete component design and select any remaining vendors*
  - *Order long lead-time components for prototypes*
  - *Update design and flight simulation and mockup*
  - *Conduct Critical Design Review (CDR)*
- Complete prototype development by providing the following:
  - *Conduct component bench tests*
  - *Initiate main rotor/ drive system qualification testing*
  - *Conduct hover rotor test on test stand*
  - *Conduct powered model rotor win : tunnel test*
  - *Update design and flight simulation and mockup*
  - *Fabricate components and subsystems for two prototypes*
  - *Assemble components and subsystems for two prototypes*
- Conduct the following system integration:
  - *Ground Run-up Test*
  - *Flight Test to expand the flight envelope &validate the flight simulation*
  - *Demonstrate GAP4 Prototype Capability to Turkish Government & Industry using two prototypes*
  - *Conduct Production Manufacturing and Certification Completion Management*
- Review for Phase II

Market Research

Small helicopters currently in production as well as the new models being developed are evaluated by the use of an evaluation criterion with which different objectives are included. This evaluation is mainly focused on two major criteria: capability and affordability. For this problem, an OEC function was selected that captures the in influence and impact of both the economics and performance aspects of this vehicle. This OEC is presented as:

$$OEC=\alpha\bullet\left(\frac{\frac{Payload\times Range}{W+W_f}}{P.I_{BL}}\right)+\beta\bullet\left(\frac{\frac{(Hoge+Hige+Serv.Ceil)/3}{HP_{inst}}}{H.C.I_{BL}}\right)+\gamma\bullet\left(\frac{LCC_{BL}}{LCC}\right) \quad (1)$$

where,

P.L. = Payload [lbs]
R = Range [nm]
We = Empty weight [lbs]
Wf = Fuel weight [lbs]
Hp = Horsepower
GW = Gross weight [lbs]
P.I = Productivity index
HCI = Hover Capability Index
LCC = Life cycle cost
BL = Baseline

$\alpha + \beta + \gamma = 1$

$$LCC = A / C + \left(\frac{TTDOC}{BT} \times UTIL \times Y\right) \quad (2)$$

where,

A/C = Acquisition cost [$]
TTDOC = Total trip direct operating cost [$]
BT = Block time [hr.]
UTIL = Utilization [hr./year]
Y = Duration of service [years]

The Productivity Index (P.I.) and Hover Capability Index (H.C.I.) were selected as the major indicators of the capability of the proposed helicopter and the Life Cycle Cost (L.C.C.) was selected as the evaluator of affordability for this vehicle. The coefficients, α, β, γ, are subjectively assigned importance factors used to weight the importance of the various terms from the evaluator's point of view. In present concept evaluation study, the P.I. was weighted the most, α = 0.45, the HCI was weighted moderately at, β = 0.15, while the LCC was weighted strongly, as γ = 0.4.

In Figure 3. GAP-4 baseline helicopter is compared with the models 4, 5, 7, and 8 and in the range of 3-4 seat helicopters. As the 7th helicopter was selected for the baseline values, GAP-4 baseline helicopter represents an improved design.

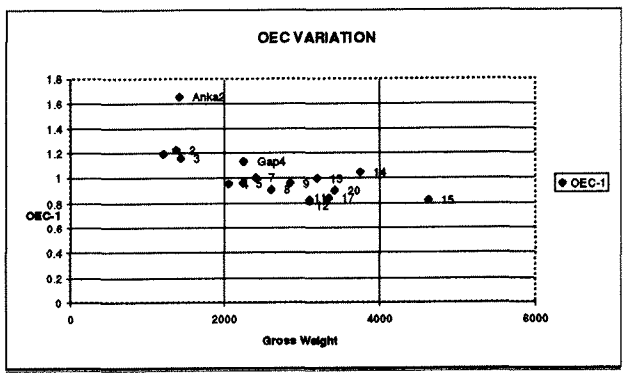


FIGURE 5- OEC values for different small helicopters.

Performance Requirements

Based on the market research evaluations and the targeted personal transportation missions of the GAP-4 helicopter, the design mission profile representing a typical flight in condition characteristics of Southeastern part of Turkey is as shown in Figure 6..

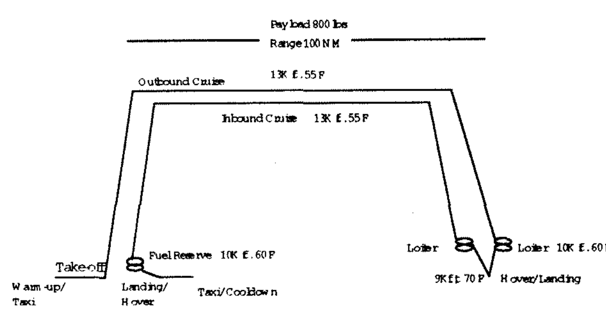


FIGURE 6- Design Mission Profile of Proposed GAP-4

The capability to hover out of ground effect (HOGE) at 9,000 ft ISA+20°C and a service ceiling of 15,000 ft ISA+10°C are two additional mission constraints which leads to a hot-day/high altitude vehicle.

Conceptual Design

Design Objectives

Based on the market research evaluations and defined requirements, several key guidelines are established for the design and development process. It is very important that the GAP-4 program be launched as soon as possible in order that the large worldwide market for a small four seat helicopter, identified by the market research, can be captured and exploited. In order to minimize risk and assure success of the GAP-4 helicopter program, only mature and proven technologies would be used. However, advanced materials like composites would be used where risk is low and a clear advantage in terms of weight reduction, structural integrity and product quality can be gained.

Based on the defined performance requirements and specifications, important design feat.res and related aircraft subsystems are evaluated by a Quality Function Deployment (QFD) Matrix as shown in Figure 5. In order to achieve the required hot-day/high-altitude hover and long range performance characteristics as well as the desired flight handling qualities and maintenance objectives, the proposed GAP-4 helicopter configuration should utilize an advanced rotor hub system and high performance engine with lower specific fuel consumption.

DIRECTION OF IMPROVEMENT			↓		↓		↑		
CUSTOMER ATTRIBUTES WHAT	DESIGN CHARACTERISTICS HOW	IMPORTANCE	Weight	Tipspeed	Disk Loading	Solidity	Power Availible	Rotor-Hub Type	Anti-torque
General	Low Purchase Cost	12	⊙	△			⊙	⊙	⊙
	Low Operating Cost	11	⊙				○	⊙	⊙
	Versatile Aircraft	8	△	△	⊙	○	⊙	⊙	⊙
Performance	Long Range	9		△	⊙	○	○	△	
	Vc=120 kts	4	△	⊙	○	○	⊙	△	
	High Hover OGE	3	⊙		⊙	⊙	⊙	⊙	
	900 lb Sling Load	6	△	△	△	⊙	⊙		
	High Auto Rotation Index	10	△	⊙	○	○		○	△
	cg Travel	5			⊙	○	⊙	⊙	△
Design Requests	Fuselage and Car Body Design	2	⊙	△					
	Landing System	7	⊙				⊙	○	
	Reduced Noise	1		⊙	△	⊙	△		⊙
ABSOLUTE IMPORTANCE			343	172	274	198	466	415	303
RELATIVE IMPORTANCE			15%	7%	12%	9%	21%	19%	13%

FIGURE 7- QFD Matrices for GAP-4 Configuration

Design Methodology

It is essential in order for any industry to be competitive, in today's highly competitive world marketplace, that they are capable of assessing early in the design process the impact of new technologies as well as the capability and affordability of their product. Furthermore, they must be able to control and manage the risk, and produce at the optimum level that yields the maximum performance and the minimum life-cycle cost to the user.

The Georgia Tech Center of Excellence in Rotorcraft Technology (CERT) has recognized the important techniques such as Concurrent Engineering, Integrated Product and Process Design, and Multidisciplinary Design Optimization (MDO) and is implementing them in the early design phases. CERT is also investigating the formulation of an Integrated Product and Process Development (IPPD) computing environment

Aircraft design optimization is usually achieved through a parametric trade-off approach where a few design variables are chosen, and a variation of these variables within the selected ranges of interest is allowed in search of an optimum response. In addition to the large number of cases that the designer has to run to obtain this solution, there is also the danger that this approach of varying one variable at the time might not reach an optimum solution. In an effort to alleviate the potential problems associated with this approach, an alternate optimization procedure is proposed in order to check the feasible design space in a more efficient and intelligent manner, increase the number of design variables considered, and reduce the overall number of design cases needed.

During the conceptual design phase of GAP-4 helicopter development, a well documented parameter design optimization was taken based on a statistical approach combining the so called Design of Experiments with the Response Surface Methodology. The design of Experiments (DOE) approach was used to identify the most significant contributing design variables to vehicle performance, economics or some combination of both which may be captured through an Overall Evaluation Criterion (OEC) function given by equation 3. Details of the DOE approach has been explained in Ref. 1.

Overall Evaluation Criterion

In order to obtain an optimum configuration, the designer must first select an evaluation criterion to evaluate the different configuration against each other. The conceptual design optimization of the GAP-4 is mainly focused on two major criteria: capability and affordability. For this problem, an OEC function was selected that captures the influence and impact of both the economics and performance aspects of this vehicle.

This OEC is presented as:

$$OEC = \alpha \cdot (\frac{\frac{P.L \times R}{We+Wf}}{P.I._{BL}}) + \beta \cdot (\frac{\frac{t/K}{GW}}{(t/K)_{BL}}) + \gamma \cdot (\frac{LCC_{BL}}{LCC}) \quad (3)$$

where,

t/K = Autorotation Index

$\alpha + \beta + \gamma = 1$

and for a conceptual design stage LCC can be established as:

$$LCC = \frac{RDT\&E}{Q} + A/C + (\frac{TTDOC}{BT} \times UTIL \times Y) \quad (4)$$

where,

RDT&E = Research development testing and evaluation cost [$]

Q = Production quantity

other parameters were defined in equation 1 and 2.

The Productivity Index (P.I.) and Autorotation Index (t/K) were selected as the major indicators of the capability and the Life Cycle Cost (LCC) was selected as the evaluator of affordability for this rotorcraft. The coefficients, α, β, γ, are subjectively assigned importance factors used to weight the importance of the various terms from the evaluator's point of view. In this study, the PI was weighted the most, $\alpha = 0.6$, the LCC was weighted moderately at, $\gamma = 0.3$, while the t/K was weighted lightly, $\beta = 0.1$. Optimization of the OEC results produced by the RSM were compared to the baseline results, yielding an improved rotorcraft design.

Responce Surface Methodology

The RSM encompasses a set of techniques by which relationships between a set of independent variables and their dependent functions can be studied empirically. Response surfaces are constructed by running a set of experiments in which certain combinations of independent variables are changed in a systematic fashion. The "response" is the outcome of each individual experiment and the response values are then used to create surface equation fits based on the various independent parameters. The surface fits can be based on any type of analytical surface: simple linear fits, quadratics, complex polynomials, etc. In this particular portion of the study, it was known in advance that some of the data would be nonlinear, so the option of using simple linear fits was immediately ruled out. Instead, a second order model was chosen to represent the response surfaces[2]. The surface fit equations are of the form:

$$Y = \alpha_0 + \Sigma_i \alpha_i X_i + \Sigma_i \alpha_{ii} X_i^2 + \Sigma_{i \leq j} \alpha_{ij} X_i X_j \quad (5)$$

The coefficients of this equation are determined through a three-level DOE. The response surface design selected for this study was based on the Box-Behnken Design (BBD) scheme. A statistical analysis tool JMP is used to set up the DOE and analyze the simulation results[3]. The power of the Box-Behnken methods can be easily recognized when one compares the number of cases needed to determine the effect of the design variables considered on the chosen response[4] (Table 1).

TABLE 1- No. of Cases to Build a 2nd-Order Model

	Response		Point
Number of Variables	**Full Factorial (3^n)**	**Central Composite Design (2^n+2n+1)**	**Box-Behnken Design**
7	**2,187**	**143**	**62**

Once the design points have been selected and analyzed, a multivariate regression is performed on the data to determine the coefficients of the quadratic RSE. The optimum parameter values are then determined using nonlinear optimization techniques. Finally, a verification experiment is performed using the "optimal" values in order to determine the predictive capability of the model. This methodology allows for rapid exploration of the given parameter space, and determination of sensitivities. It also allows for easy modifications to the constraint bounds without having to go back and perform additional experiments.

TABLE 2- Selected Variables for DOE

CAPABLITY

No	Variable	min	max	unit	remark
1	R_{mr}	12.6	13.6	ft	MR radius
2	DL	3.8	4.1	lbs/ft^2	disk loading
3	Θ_{tw}	-8	-12	deg	MR twist
4	V_{tip}	680	710	ft/sec	MR tip speed
5	C_t/σ	0.068	0.095		blade loading
6	FPDB	8	12	ft^2	fuslg f.p. drag area
7	W_{tip}	0	1	lbs	MR tip weight
8	Eng. Typ	1	3		Engine type

AFFORDABILITY

No	Variable	min	max	unit	remark
1	#A/C	800	1200		production quantity
2	BHPY	800	1400	hr/year	annual utilization
3	RATEL	8	14	$/hr	main labor rate
4	TBO	400	800	hr	eng. time between overhaul
5	TBDOS	400	600	hr	dynamic systems TBO
6	SPARF(1)	2	4	%	airframe spare factor
7	SPARF(2)	1	3	%	engine spare factor
8	SPARF(3)	3	5	%	dynamic systems spare factor

As a first step, sixteen design variables were selected are listed in Table 2. Since no *a priori* knowledge existed as to which variables were important, a Screening Test (ST) had to be performed. The ST is used to identify primary contributing factors among a set of design variables in a two-level (minimum and maximum) during the DOE phase. Through this screening test, the seven most contributing design factors were identified

Subsequently, a three-level DOE can be prepared using low, medium, and high bound values for the surviving valuables to form the corresponding response surface. Based on the seven major contributing design factors, the Box-Behnken design required sixty two experiments. The simulating results were calculated using Georgia Tech Preliminary Design and Performance (GTPDP)[5] code/Helicopter Sizing. The Pareto plot in Fig.8 depicts the order of significance of design factors to the OEC. Based on the Design Parameter Estimates given in Table 3 an OEC equation was formulated as follows:

$$
\begin{array}{rlcl}
\textbf{OEC}= & 17.69 & * & C_t/\sigma \\
- & 18.23E\text{-}4 & * & BHPY \\
+ & 0.2526 & * & CG \\
+ & 37.15E\text{-}3 & * & RATEL \\
+ & 14.39E\text{-}3 & * & V_{tip} \\
+ & 33.67E\text{-}3 & * & FPDB \\
+ & 0.3907 & * & R \\
- & 77.5 & * & (C_t/\sigma)^2 \\
+ & 4E\text{-}7 & * & BHPY^2 \\
- & 3.6E\text{-}5 & * & (CG*BHPY) \\
- & 3.0875E\text{-}2 & * & CG^2 \\
+ & 1.22E\text{-}5 & * & RATEL*BHPY \\
- & 1.297E\text{-}3 & * & RATEL^2 \\
+ & 1.1E\text{-}2 & * & V_{tip}*C_t/\sigma \\
+ & 8E\text{-}7 & * & V_{tip}*BHPY \\
- & 3.5E\text{-}5 & * & V_{tip}*CG \\
- & 1.1E\text{-}4 & * & V_{tip}*RATEL \\
- & 1.2E\text{-}5 & * & V_{tip}^2 \\
- & 1.25E\text{-}1 & * & FPDB*C_t/\sigma \\
- & 2.5E\text{-}5 & * & FPDB*V_{tip} \\
- & 6.72E\text{-}4 & * & FPDB^2 \\
- & 2.25E\text{-}3 & * & R*CG \\
+ & 4.5E3 & * & R*RATEL \\
+ & 2.8E\text{-}4 & * & R*V_{tip} \\
- & 2.5E\text{-}2 & * & R^2
\end{array}
$$

This quadratic OEC equation can be used to rapidly determine the effect of varying design parameter values on the response characteristic. A major advantage of this approach is that sensitivity studies can be carried out without the need to reanalyze the entire system after each change of design variables. The coefficient of determination, R^2, which expresses the pc tion of the total variation in the dependent variable explained by the regression line, indicated that 99.9% of the total variation in OEC may be represented by the regression equation using these seven input parameters.

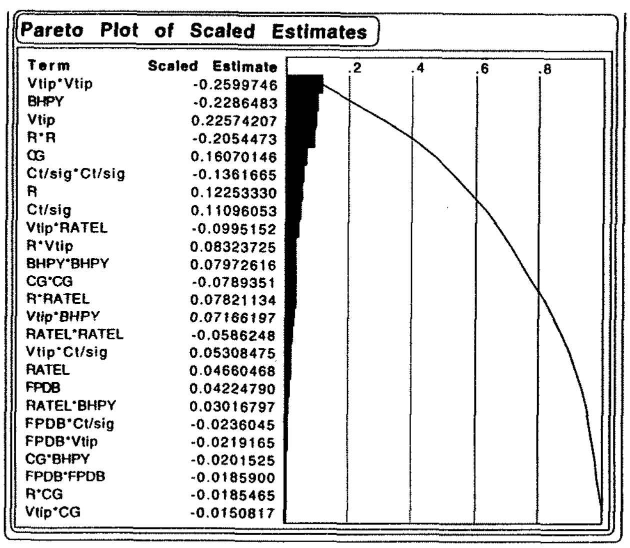


FIGURE 8- Three Level Pareto Plot

TABLE 3 - RSM Design Parameter Estimates,

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-7.956498	2.697913	-2.95	0.0056
Ct/sig	17.69	7.40367	2.39	0.0222
BHPY	-0.001823	0.000310	-5.88	0.0000
CG	0.2562	0.080228	3.19	0.0029
RATEL	0.0371500	0.042542	0.87	0.3883
Vtip	0.0143957	0.004434	3.25	0.0025
FPDB	0.0336771	0.033474	1.01	0.3211
R	0.3907000	0.208200	1.88	0.0687
Ct/sig*Ct/sig	-77.5	16.14646	-4.80	0.0000
BHPY*BHPY	0.0000004	4.037e-8	9.79	0.0000
CG*BHPY	-0.000036	0.000010	-3.40	0.0017
CG*CG	-0.030875	0.001615	-19.12	0.0000
RATEL*BHPY	0.0000122	0.000005	2.32	0.0259
RATEL*RATEL	-0.001297	0.000404	-3.21	0.0028
Vtip*Ct/sig	0.011	0.008390	1.31	0.1981
Vtip*BHPY	0.0000008	4.195e-7	1.97	0.0570
Vtip*CG	-0.000035	0.000084	-0.42	0.6790
Vtip*RATEL	-0.00011	0.000042	-2.62	0.0127
Vtip*Vtip	-0.000012	0.000003	-4.68	0.0000
FPDB*Ct/sig	-0.125	0.104874	-1.19	0.2411
FPDB*Vtip	-0.000025	0.000042	-0.60	0.5549
FPDB*FPDB	-0.000672	0.000404	-1.66	0.1047
R*CG	-0.00225	0.004195	-0.54	0.5950
R*RATEL	0.0045000	0.002097	2.15	0.0387
R*Vtip	0.00028	0.000168	1.67	0.1039
R*R	-0.025	0.006459	-3.87	0.0004

A prediction profile is defined as the predicted response as one variable, which is changed while the rest are held constant at their current values. The prediction profile was in the quadratic form due to the three level experiment (Fig. 9).

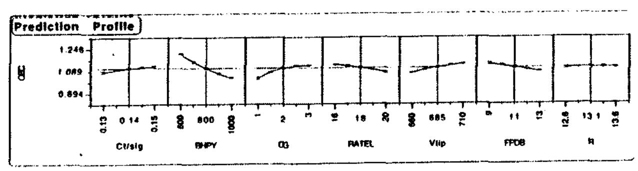


FIGURE 9- Prediction Profile for OEC

Using the prediction profile prescribed in Fig.9, the optimal settings for each variable were selected so as to maximize the OEC. For these levels, both sizing code and the RSE yielded an OEC value of 1.24. This corresponds to 24% improvement of OEC with respect to reference existing small helicopters.

Aircraft Description

The configuration selected for the GAP-4 helicopter represents an optimum synthesis of the best features of a number of helicopter designs that have been extensively review and evaluated. The features selected will make possible the most mission versatile, cost effective helicopter available in its class for the foreseeable future. Side and front view of the GAP-4 conceptual design are presented in Figure 10. The chosen configuration consist of a four bladed, bearingless main rotor for low vibration, excellent maneuverability and reduced parts count; a protected tail rotor for safety and low noise; a tricycle wheeled landing gear for ease of handling/taxiing/takeoff and reduced likelihood of mechanical instability; a very compact single aerodiesel engine that is insensitive to altitude/temperature variations; and a fuselage/cabin that confortably seats four people (or five if a bench seat is used). Technologies are judiciously used to combine capability enhancements with lower cost.

Other Significant Design Features

The structure of the GAP-4 helicopter consists principally of low cost composite materials with metal used only where factors such as cost, ease of manufacture and load path efficiency dictate its usage. Only two major assemblies, the cabin and the fuselage, make up the structure of the GAP-4 helicopter. The cabin and fuselage are designed to be quickly separated within a matter of a few hours to permit a quick replacement of the four place cabin with a different cabin designed to accommodate one of the alternate missions of aerial observation and surveillance, basic EMS utilization and agricultural application.

This "quick change" feature is made feasible by containing the fuel tanks fuel feed system, as well as other high cost subsystem, within the fuselage,thus avoiding their disturbance when the cabin is removed. Only a small number of structural load carrying bolts, fairing screws, cables, pushrods and electrical connectors have to be disconnected to separate the two assemblies. The engine, main rotor drive system, tail rotor drive system and fuel system comprise the major high cost subsystems contained within the fuselage. Four seat cabin configuration of GAP-4 is shown in Fig. 11.

Engine

In order for the proposed GAP-4 helicopter to meet the defined requirements relating to hot-day/high altitude operations, high cruise speed as well as low acquisition and direct operating cost, the engine has to exceed by a significant margin the horsepower to weight ratio of existing piston engines. It must also demonstrate a much lower specific fuel consumption than any existing piston engine. Fortunately for the GAP-4 program, a project was started twelve years ago in Germany to develop a series of aero diesel aircraft engines covering a horsepower range from 70 hp to 300 hp that will achieve these objectives.

Some of the significant advantages offered by the Zoche 8 cylinder aero-diesel engine shown in Fig. 12 are listed as below:

- Very low vibration level
- Good reliability and low maintenance cost
- No electromagnetic interference
- Very low noise emission
- Easy to operate
- Reliable starts at low temperatures
- Safe electrical power
- Enviromentally progressive
- Minimal cooling air requirement

Specifics of the Zoche ZO 02A diesel engine are given as:

Power	220 kW • 300 hp
Displacement	5.33 liter • 325.3 cu inches
Height, width and diamet.	644 mm • 25.4 inches
Weight	123 kg • 271 lbs
Bore / Stroke	95 / 94 mm • 3.74 / 3.70 inches
Compression Ratio	17:1
Intake Manif. Temp.	80° C • 176° F
Max Power BSFC	225 g/kWh • 0.365 lb / hp hr
Cruise (75%) BSFC	220 g/kWh • 0.357 lb / hp hr
Cruise (75%) Consump.	43.7 liter / hr • 11.43 gal / hr
Fuels	Diesel Fuel # 2, Jet Fuel JP-4, JP-5, JP-8, Jet A

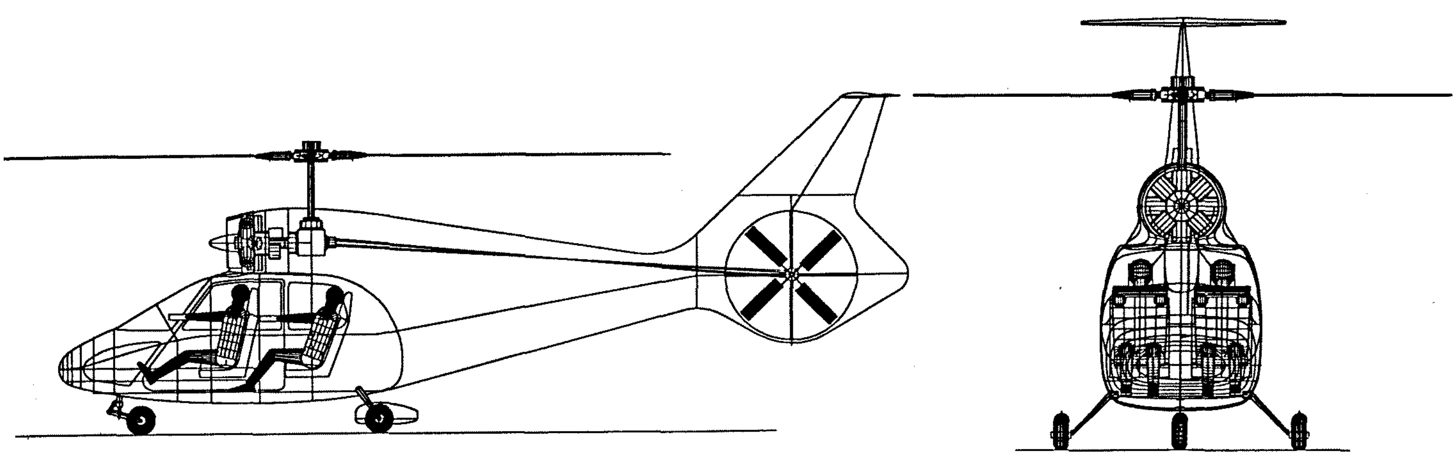
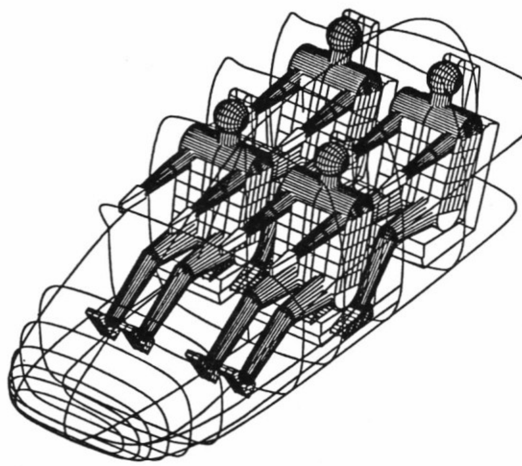


FIGURE 10- Side and front view of the proposed GAP-4 helicopter.



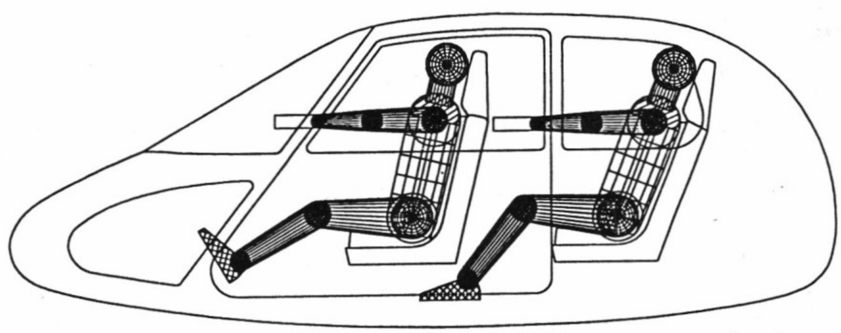


FIGURE 11- Four seat cabin arrangement

TABLE 4- Basic Physical Parameters

Parameter	Main Rotor	Tail Rotor
Radius (ft)	13.1	2.1
Number of blades	4	4
Airfoil	VR-07	NACA0012
Blade Chord (ft)	0.53	0.4
Solidity	0.048	0.12
RPM	518	3100
I_b (slug.ft^2)	41.9	
Twist (deg)	-8	0
MR Blade Lock No.	4.53	
Aerodynamic Surfaces	Horizontal Stabilizer	Vertical Tail
Aspect Ratio	2.36	3.1
Area (ft^2)	3.44	2.14
Incident Angle (deg)	9.8	1

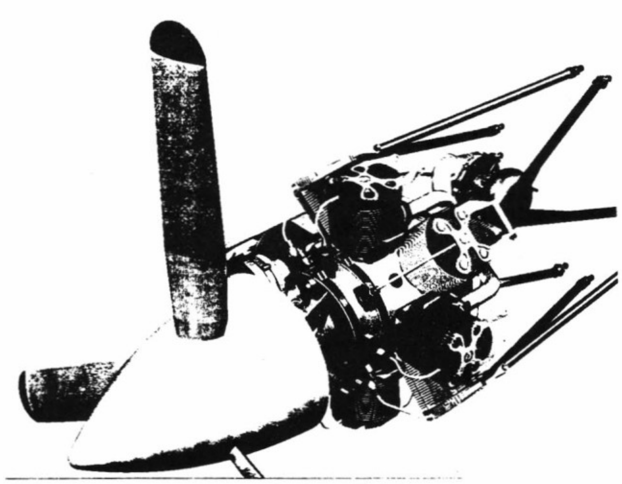


Figure 13. Zoche ZO 02A 8 cylinder aero-diesel engine.

TABLE 5- Weight Distribution

Weights	lb	kg
Empty	1225	555
Design Gross	2250	1019
Max Takeoff	2450	1110
Fuel	175	79
Max Payload	850	385

Basic physical parameters of the GAP-4 helicopter is listed in Table 4 and weight distribution of the vehicle configuration is also listed in Table 5.

Performance Capabilities

Results of the GAP-4 helicopter conceptual design studies have indicated that design performance characteristics of the selected optimized configuration have exceeded the several initial design requirements. As being compared with the previous Market Research results the GAP-4 helicopter represents a significant potential for filling an existing ***gap*** between the present piston engine helicopters with the turbine powered ones in the range of four to siz seats..

GAP-4 helicopter is capable of performing below listed missions::

Cruise Mission: Hover, take-off landing at 9,000 ft/90 F and cruise at 13,000 ft/75F range of 255 NM (20 min. reserve) with (pilot+3 passenger) or 450 NM (20 min. reserve) with (pilot+2 passenger).

Aerial Patrol & Surveillance: Hover, take-off landing at 9,000 ft/90 F and cruise at 13,000 ft/75F 6 hours of loitering with pilot+1passenger.

Agricultural Application: Operating at 10,000/80F 850 LB chemical spraying and 45 min. contour flying.

Finally major performance characteristics of GAP-4 are given in Table 5.

TABLE 5- Major Performance Characteristics

	DESIGN GROSS Weight		MAX.TAKEOFF Weight	
	ISA,SL	13kft 55F	ISA,SL	13kft 55F
V(bestrange) (kts)	87.2	92.7	86.9	92.7
Spec. Range (nm/lb)	1.119	1.44	1.124	1.46
Fuel (lb)	175	175	250	250
Range (nm)	196	252	281	365
V(endurance) (kts)	49.5	61.7	49.2	61.1
Endurance (hr)	3.025	3.2	4.37	4.68
HOGE Ceiling	STD		19000 ft	
	30° C		11000 ft	
Service Ceiling	STD		25000 ft	
ROC	SL/STD		1571ft/min	
Vmax	ISA,SL		106.4kts	
	13kft/ 55F		109.6kts	
Vcruise	ISA,SL		106.4kts	
	13kft/ 55F		109.6kts	

Conclusions

Results of conceptual design and proposal development studies have indicated that the proposed GAP-4 Helicopter Development and Production Project perfectly matches Turkey's several national objectives in aviation industry.

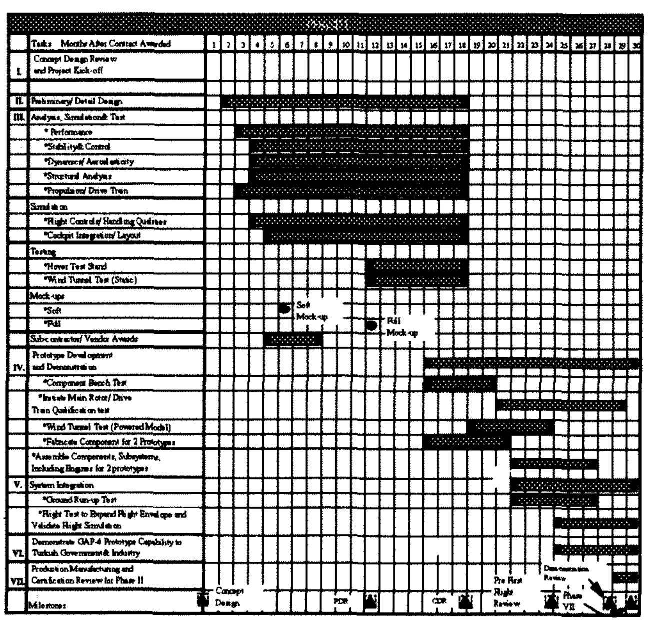


FIGURE 14- Proposed Schedule for the GAP-4 Project.

First of all GAP-4 will be a product which specificly fullfil Turkey's multi-purpose small helicopter need and it represents a potential for capturing a significant portion of world's piston engine small helicopter market. Secondly the GAP-4 Project will be the best approach to foster a national helicopter industry whereas Turkish Armed Forces have recently estimated need of 800 helicopters for the next 25-30 years[6] and Turkish Industry is urged to gain capabilities towards the fulfillment of this national needs.

One of the most significant aspect of the porposed project is that GAP-4 Development and Production Project can be an excellent for a multi-national university/ government/industry collaborative development project for Turkey.

Acknowledgement

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REFERENCES

1) Kim, Ho S., Mavris, D., Virasak J., Schrage, D.P., "Selection and Design Optimization of a High Speed, Highly Maneuverable Rotorcraft Configuration," American Helicopter Society 51st Annual Forum, Fort Worth, Texas, May 1995.

2) Cornell, J.A., "How to apply Response Surface Methodology," American Society for Quality Control, Statistics Division, 1990.

3) "JMP Statistics and Graphics Guide Version 3," SAS Institute Inc., 1994.

4) Meyers, R. H., "Response Surface Methodology," Allen and Bacon Inc., MA, 1971.

5) Mavris, Dimitri, Preston, John R., and Schrage, Daniel P., "Georgia Tech Preliminary Design and Performance," Georgia Institute of Technology, Atlanta, Georgia, March 1991

6) Briefing Notes of Turkish Armed Forces April 4, 1996.