Outline Design of Compact GNC Module For Missile Flight Control Purposes

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To ensure that the guided rocket missile could be in position to follow pre-defined flight trajectory, a lot of very sophisticated equipment has to be involved in. From a practical point of view and if the general design of the missile allows that, the necessary subsystems to be used in missile flight control purposes have to be assembled as a separate whole (one segment /module of the missile). If this concept is acceptable, two problems have to be solved during the designing: achieving of the satisfactory ratio between load capacity (warhead) and total weight of the missile (that includes the appropriate subsystems for guidance, navigation and control of the missile too) and minimization /optimization of the used space.
The outline design of compact Guidance, Navigation and Control Module (short: GNC Module) which consists of the subsystems mentioned before is presented in this paper.

Keywords: *GNC module, instumental module, inertial navigation, aerodynamical breaks, actuator with grid fin.*

1. INTRODUCTION

One of the most important parts of the guided missile is its instrumental module. It can be called brain of the guided missile. It always contains all guidance instrumentation, and sometimes also other parts like control system, power supply, etc.

In this design we tried to make instrumental module as a compact system, which includes all guidance and control subsystems (sensor block / inertial measurement unit), guidance computer, actuators, aerodynamic brakes, control surfaces, power supply). Such design, with all systems in one block facilitates design and development, without long cabling, and also makes excellent packing of the system.

In this introductory paper, only general system design and characteristics will be discussed, while details of each subsystem will be discussed in separate papers.

Generally, all subsystems were designed with state-of-art technologies and design methods in order to get the best performance.

Some design details are unique, applied (at least according to our knowledge) for the first time.

2. DESIGN OF THE GNC MODULE

GNC module is incorporated in the missile (Fig.1 and Fig. 2) and the basic purpose of the module is to make possible the guidance and control of the missile.

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GNC module has to provide the appropriate environment for placing the equipment including the actuator system with control surfaces, as well as all necessary electronic equipment (inertial navigation system, on-board computer, power supply and power distributors, etc).

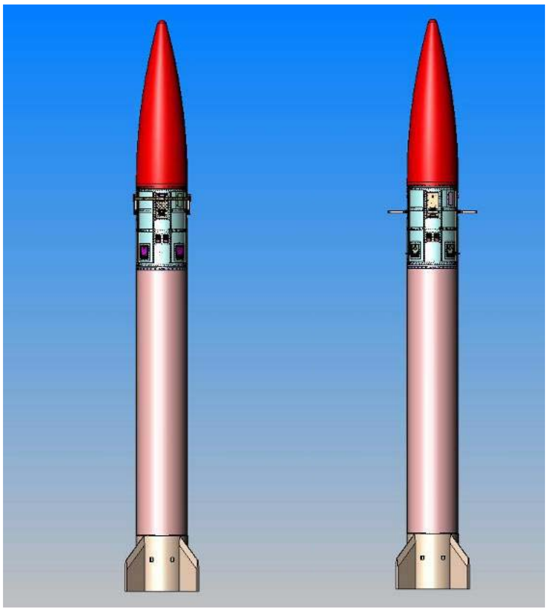

Figure 1. Missile with GNC Module

This module was designed and developed for an inertially guided short-range ballistic missile. It is placed in the space between solid propellant rocket motor and warhead. Missile concept requires guidance during all flight (including boost-phase and inertial flight phase). Control system is aerodynamic surfaces (canards).

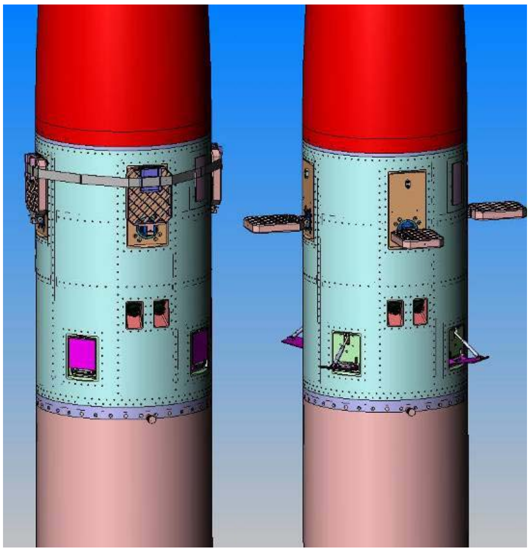

Figure 2. GNC Module: left - control surfaces and air brakes in retracted position; right - control surfaces and air brakes in operational position

3. MAIN SUBSYSTEMS OF THE GNC MODULE

GNC module consists of a few main subsystems that are shown in Fig. 3 and Fig. 4.

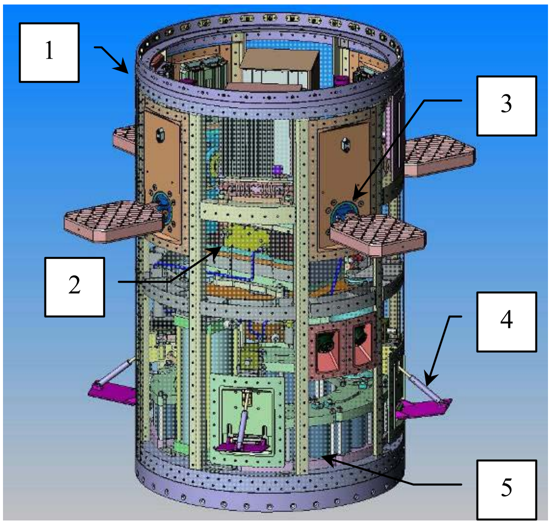

Figure 3. GNC Module with main subsystems

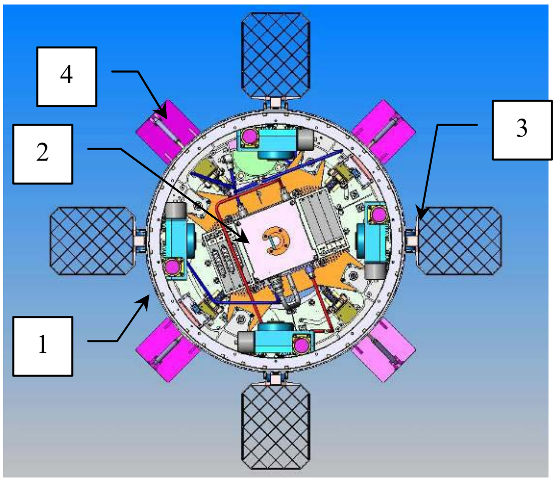

Figure 4. GNC Module with main subsystems (top view)

The following subsystems incorporated in GNC module should be considered as the main:

GNC structure /position 1/
Inertial navigation subsystem (INS) /position 2/
Actuator with grid fin /position 3/
Aerodynamic breaks /position 4/
Power supply /position 5/

The module contains a lot of accompanied subassemblies that are not of crucial importance but they are also very necessary for the mission.

3.1 GNC Structure

The structure of the GNC module (Fig. 5) offers the environment for appropriate incorporation of all the components that are required for guidance and control inside it. At the same time it represents transition segment between warhead and rocket engine and it has to have sufficient strength to carry all predicted loads.

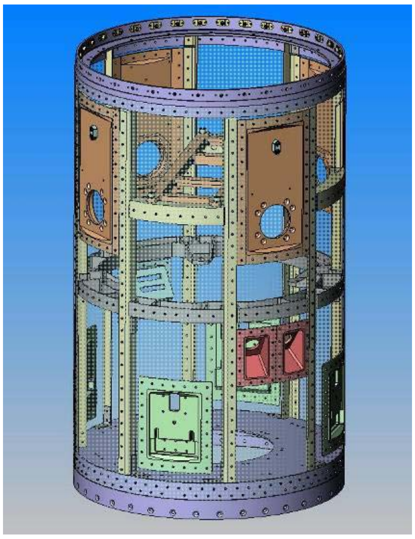

Figure 5. Structure of the GNC Module

GNC structure is completely made of AISI 2024 aluminum commonly used in aircraft industry. It is riveted structure, painted with heat-resistible paint.

Figure 6. Structure of the GNC Module (prototype)

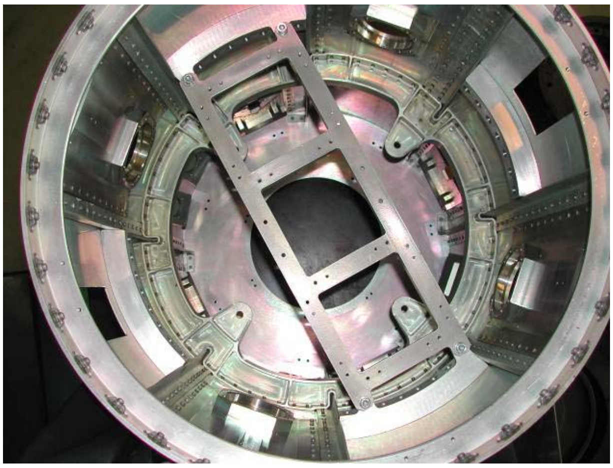

Figure 7. Structure of the GNC Module (prototype) – top view

3.2 INS Subsystem

The INS (Fig. 8) determines the position of the missile during the mission. It is completely autonomous system based on inertial sensors, gyros and accelerometers.

Basically, INS consists of:

- Inertial measurement unit (IMU) Block
- Sensor Block
- A/D Conversion & Interface
- Control Electronics Block
- Gyro Control & Power Supply
- Processor

The Sensor Block contains the motion sensors: gyros and accelerometers. The A/D Conversion & Interface converts the analog signals from the sensors and makes appropriate interface to the processor. The Gyro Control & Power Supply provides drive for the gyro motors, feedback circuit for gyro torques and power supply for accelerometers. The processor reads sensor signals and performs the INS algorithm.

The signals from inertial sensors in the Sensor Block are supplied to the analog to digital converter (ADC) where they are A/D converted. The Sensor Block also has temperature sensors. Their outputs are also converted by ADC.

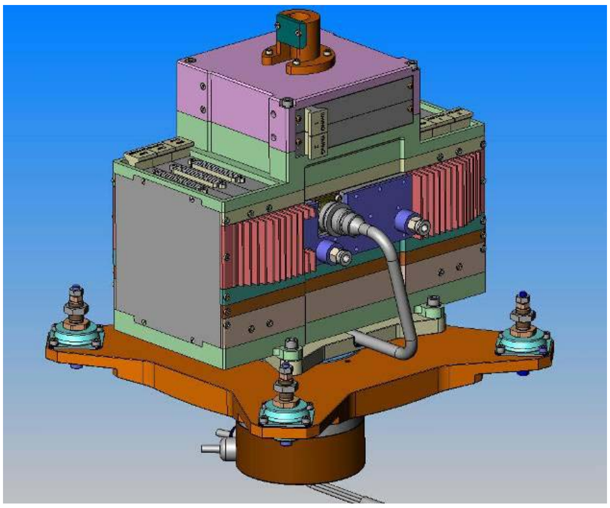

Figure 8. INS Subsystem with rotation platform

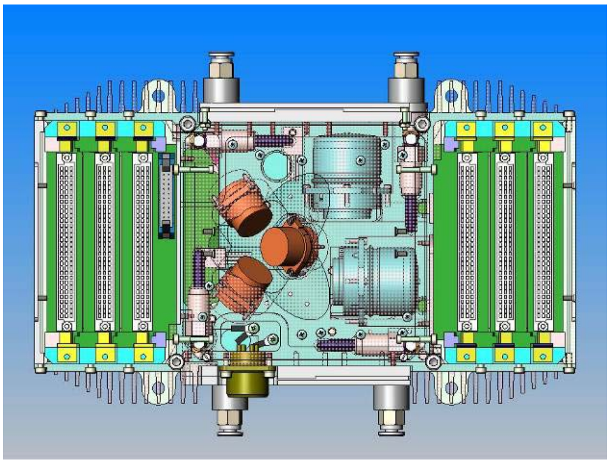

Figure 9. Inertial measurement unit (IMU Block) with electronics

All the data collected by the ADC's in the IMU Block (Fig. 9) are multiplexed in one SPORT (Analog Devices standard synchronous serial communication standard) link and supplied to the Processor in the Control Electronics Block.

For proper operation of the sensor block, gyros have to be electronically controlled and accelerometers need appropriate power supply. Gyro Control & Power Supply circuit performs this task.

For the proper operation of the INS, thermal stability is essential. Therefore, the whole body of the INS is thermally stabilized to the operating temperature. The temperature control is done by the Processor. The temperatures of the IMU block are supplied to the Processor through the same SPORT as the sensors signals. The Processor controls the heating power of the heaters by its parallel ports with ON/OFF pulse modulation algorithm. The Processor reads the data from the IMU Block and calculates the instantaneous linear[1] and angular[2] position.

Before the missile launch, when the launching ramp is erected to the initial position, the INS has to determine its initial angular position (self alignment procedure). During the self alignment procedure, the INS is rotated slowly one or more whole turns and the output of the sensors is collected and then processed to find angular position. For that purpose, the rotation platform (Fig. 8) as the part of INS subsystem is used.

IMU generates heat during its work. This heat must be transferred to surrounding to prevent overheating of electronic hardware and thus possible damage of some component and malfunctions of whole system. So, thermal control is an important part of the design criteria for IMU block to keep the component junction temperatures at reasonable levels and to provide a thermal environment which allows the electronic components and sensors to perform at their specified level. As internal electronic and sensors also should be isolated from external environment, cooling system should provide transferring heat from IMU block during missile flight.

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[1] Coordinates in some reference coordinate system

[2] Angles between the INS coordinate system and some reference coordinate system

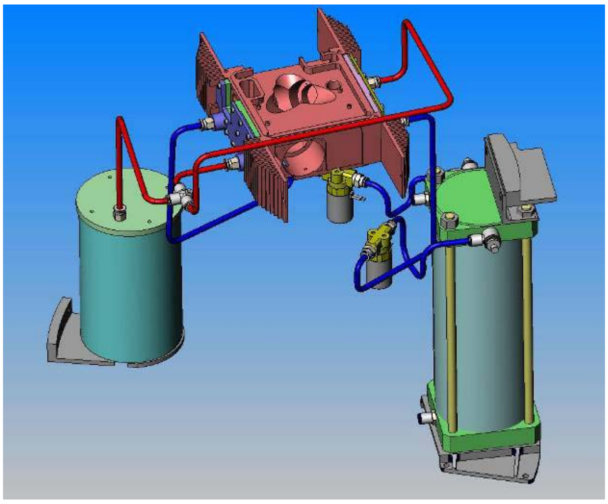

Figure 10. Cooling system for IMU

As missile and all components which are embedded into it have been exposed to influences of different accelerations during flight in various ambient conditions, analysis of possible thermal control techniques has shown that indirect forced-liquid cooling is the best solution for removing heat from electronic box. This system will offer excellent cooling performance, while large quantities of cooling liquid are not necessarily required, thus avoiding excessive weight.

In presented design (Fig. 10), the cooling liquid from reservoir is flowing under pressure through the hoses to the heat exchanger, which is connected with cold-plates on the lateral side of IMU block. Heat generated from each electronic component or sensor is conducted through its own media to the cold-plates of the enclosure, and then transferred to the surrounding liquid flowing through the heat exchanger. The liquid temperature increases as the liquid moves along the length of the channels of heat exchanger, and in this way liquid is further transferring heat from IMU block. Liquid flow is varied with a calibrated adjusting valve, which is restricting the liquid flow to the heat exchanger. All cooling liquid after flows through heat exchanger is collected in a reservoir, to prevent its spilling in the surrounding.

3.3 Actuator with grid fin

The conception of electro-mechanical actuator (Fig. 11) used in presented GNC module understands that the fin is directly integrated to the actuator (without intermediary mechanism). The housing withstands all loads that exist on the fin during the flight.

Elementary subassemblies of the electro-mechanical actuator are as follows:

DC motor & Planetary gear head /position 1/
Hosing assembly /position 2/
Screw Shaft-Nut with balls /position 2 - inside/
Lever with Sliders /position 2 - inside/
Grid fin /position 3/
Power electronic driver /position 4/

The electromotor and gear head, in the combination with transroll roller screw, transforms rotational motion

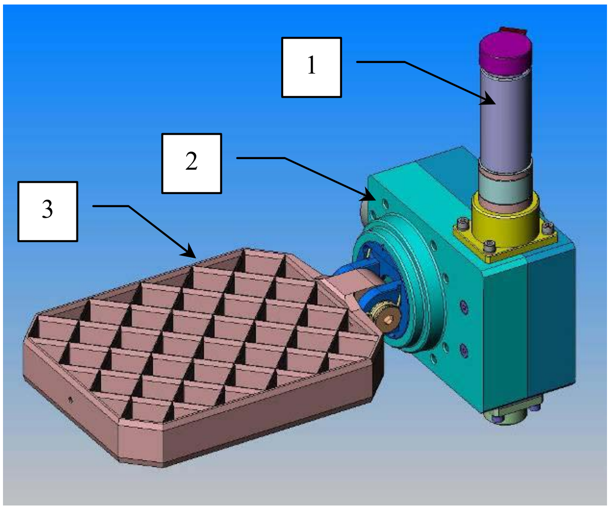

Figure 11. Actuator with grid fin

(of the electromotor) in translational motion of nut then the fork lever transforms translational motion of nut into rotational motion of fin's shaft.

Depending of the appropriate relations between the motor characteristics and the mechanical parts that are used in presented design, the maximum deflection of fin and maximum frequency of the movement could be in accordance with the requirements.

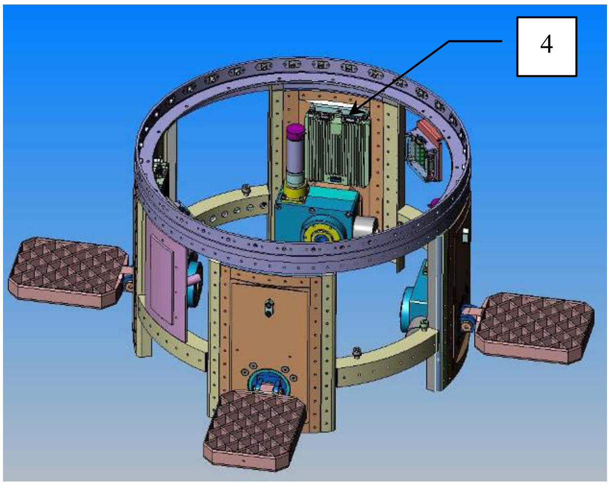

Figure 12. Section of the GNC module with position of the four actuators with grid fin

Power electronic driver is controlled by digital signal processor and it is used to control the DC motor.

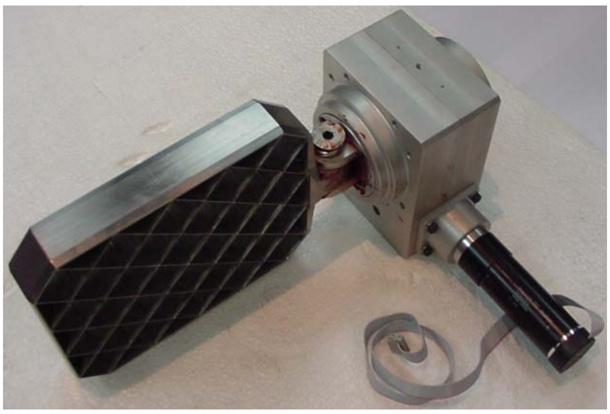

Figure 13. Actuator with grid fin (prototype)

3.4 Aerodynamic breaks

Adopted rocket engine with solid propellant for this missile does not have a device for cutting-off the burning at the moment of achieving desired calculated velocity. In that way, significant variations of needed velocities at the end of burning time (active phase) occurs, which leads to dissipation of missile's hitting precision? That could be a consequence of technological problems in solid propellant production, arising with variations of specific impulse, burning rate, propellant density, as well as precise amount of solid propellant needed for rocket engine.

The aerodynamic breaks (Fig. 14) are implemented in order to compensate velocity dissipations at the end of engine burning time, which will eventually lead to better homing on target and increasing of hitting precision.

A completely new algorithm of the trajectory-following guidance, including aerodynamic brakes was developed, as a completely new method.

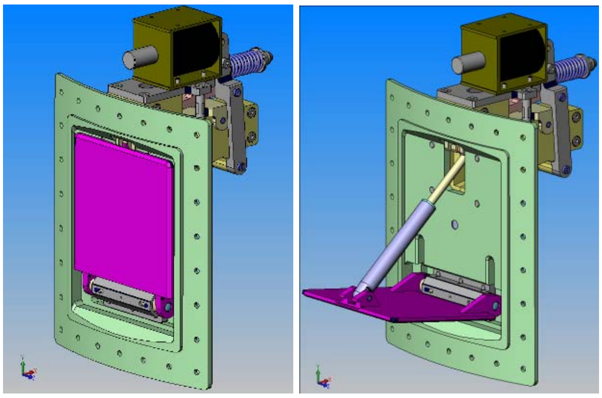

Figure 14. Aerodynamic break in closed and opened position

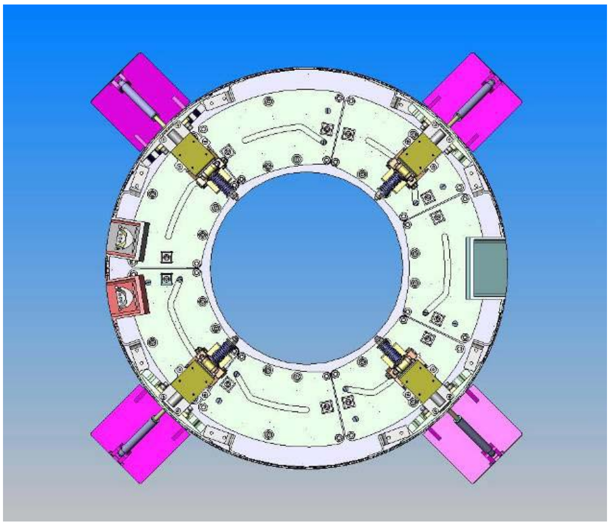

Figure 15. Section of the GNC module with position of the four aerodynamic breaks

In the case that desired velocity at the end of engine burning time is achieved, aerodynamic brakes will not be activated, and must remain locked, i.e. closed until the end of flight.

In the case that desired velocity at the end of engine burning time is exceeded, aerodynamic brakes will be activated - open, thus decreasing the velocity until desired. When that speed is reached, control system will send the signal for their immediate rejection.

Opening time for all four brakes is synchronized with very small delay in order not to occur the disturbance of trajectory. The time of rejection is synchronized for all four brakes too.

Opening and rejection of the aerodynamic breaks is controlled by Processor using DC solenoid for the command execution.

This subsystem is able to withstand aerodynamic loads with positive margins of safety.

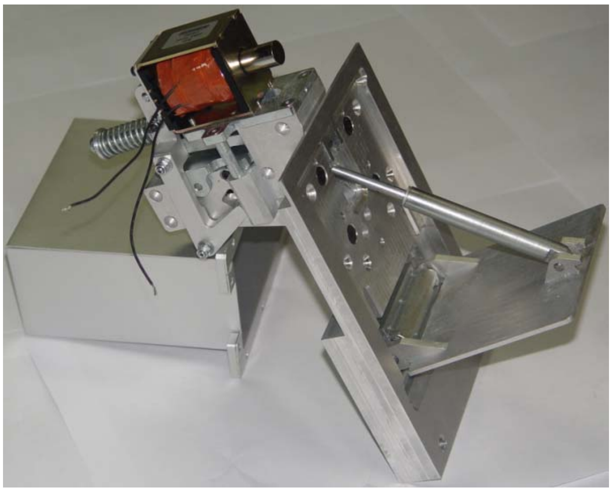

Figure 16. Aerodynamic break (prototype)

3.5 Power supply subsystem

Power supply subsystem represents a powerful source of electrical energy that makes possible the proper work of all electrical systems during the flight.

The system comprises six single units (modules), each containing seven high-quality thin plate lead rechargeable cells (Fig. 17). The selected cells are with sealed constructions using a starved electrolyte system, providing numerous advantages including long service life, rugged constructions, extreme temperature performance, fast recharge, high discharger rates and low internal resistance. In addition to the standard cylindrical configurations, chosen cells offer a high degree of flexibility to meet unusual requirements.

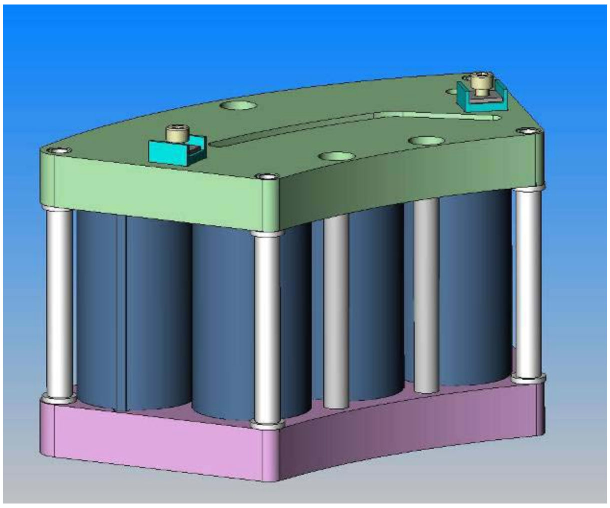

Figure 17. One module of the power supply subsystem

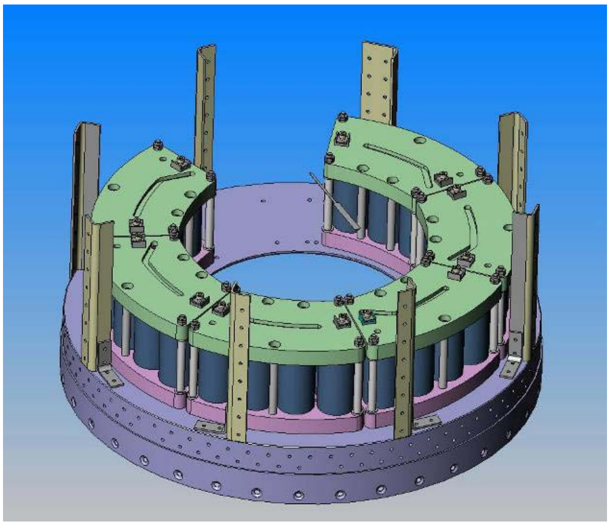

Figure 18. Section of the GNC module with position of the power supply subsystem

4. CONCLUSION

After successful ground and flight tests, we can conclude that the design concept was successfully selected, and all preliminary requirements were accomplished. Compact design enabled complete system servicing and especially testing very easily manageable.

During the tests we got the following results:

- All the systems worked properly with required performances, which proved their design constrains.
- Structural loads were in predicted limits.
- Missile flight was stable and controllability good.
- INS precision is according to predicted performance.
- Aerodynamic properties of grill-canard were in required limits.
- Temperature profiles on the outer surface and inside module were in good agreement with predicted values.
- Temperature control of the INS was functioning in predicted limits (+/- 0.1 C).
- New guidance algorithm, with brake control, worked excellently.
- Natural control autopilot was proven as stable and with good dynamic characteristics.

We can finally conclude that all new systems (grid-fins, natural control, brake-control guidance, INS algorithm, temperature control algorithm) were flight proven.

5. ACKNOWLEDGMENT

The authors would like to emphasize an important fact that presented design would never be realized without our colleagues: Milan Milisavljevic, B.Sc., Goran Kalba, B.Sc. and Vladica Bozic, Ph.D. At the same time we woud like to express our great gratitude for their help.

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КОНЦЕПЦИЈА КОМПАКТНОГ ГНЦ МОДУЛА ЗА УПРАВЉАЊЕ ЛЕТОМ ПРОЈЕКТИЛА

Ђорђе Благојевић, Марко Милош

Да би се обезбедило да вођени пројектил буде у могућности да прати унапред задату путању лета велика количина софистициране опреме мора да буде укључена у то. Са практичне тачке гледишта и ако то конструкција пројектила дозвољава, неопходни подсистеми који морају да буду коришћени за управљање летом пројектила требало би да буду засебна целина (један сегмент / модул пројектила). Уколико је то прихватљив концепт, два проблема треба да буду решена током пројектовања: постизање задовољавајућег односа између корисног терета (бојева глава) и укупне тежине пројектила (укључујући одговарајуће подсистеме за вођење, навигацију и управљање) и минимизација / оптимизација искоришћеног простора.

Концепција компактног модула за вођење /енгл.: Guidance/, навигацију /енгл.: Navigation/ и управљање /енгл.: Control/ (скраћено: ГНЦ модул) који се састоји од поменутих подсистема је презентована у овом раду.