Development and Tests of an Automatic Decking System Demonstrator of VTOL UAV on Naval Platform

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ABSTRACT

SIREHNA has developed, for the French Ministry of Defence, a demonstrator of an automatic decking system for VTOL UAV on naval platform.

This system allows to:

- *Accurately and continuously measure the position of the UAV with respect to the centre of the landing platform, before and after touchdown. This is achieved through real time hybridization of inertial and GPS measurements performed onboard the UAV and onboard the vessel.*
- *Define the optimum date and platform position for touchdown (target point just before the platform goes down). This is achieved by means of a ship motion prediction method which exploits the ship motion measured by the shipborne part of the system.*
- *Define the approach trajectory and velocity profile according to the target point position and date, to the ship route and to environmental conditions. The trajectory is regularly updated during the approach, until touchdown accounting for continuous updates of the ship motion measurements and predictions and of the UAV position measurements.*
- *Transmit in real time to the UAV flight control system guidance commands in order to have the UAV follow the decking trajectory.*

The system demonstrator is composed of an airborne unit and a shipborne unit, both composed of an Inertial Measurement Unit, a GPS receiver and a real time computer which performs data acquisition, and INS/GPS hybridization for delivering navigation solutions for the UAV and the ship. Hybridization of aerial and ship navigation solutions, to obtain relative position, ship motion prediction, using measured ship motions, approach and decking trajectory definition and closed loop command of the UAV are also hosted by the shipborne computer.

The system demonstrator has been developed and various levels of tests have been performed:

- *Numerical simulations, by means of a simulation platform designed and implemented specifically for the project.*
- *Physical simulations at reduced scale by means of AUV and decking platform simulators, also designed and constructed specifically for the project.*

Doucy, O.; Cellier, N.; Corrignan, P. (2007) Development and Tests of an Automatic Decking System Demonstrator of VTOL UAV on Naval Platform. In *Platform Innovations and System Integration for Unmanned Air, Land and Sea Vehicles (AVT-SCI Joint Symposium)* (pp. 14-1 – 14-10). Meeting Proceedings RTO-MP-AVT-146, Paper 14. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 NOV 2007	**N/A**	**-**

4. TITLE AND SUBTITLE **Development and Tests of an Automatic Decking System Demonstrator of VTOL UAV on Naval Platform**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **SIREHNA 1, rue de la Noe BP42105 44321 Nantes Cedex 3 FRANCE**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM202416., The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**10**	

- *Physical simulations at full scale with a real unmanned helicopter, equipped with the airborne unit of the system, on the decking platform simulator. In this purpose, the decking platform simulator has been designed to have a compact device, easily transportable and installable, and allowing safe decking tests for the UAV.*

All tests were performed on the basis of realistic scenarios representing decking on a frigate, with platform motions representative of sea state 5, and various wave incidences.

This paper presents the system principle and main components, the tests performed and results obtained, as well as future envisaged developments

1.0 INTRODUCTION

In the frame of a « Plan d'Etude Amont - PEA » (upstream study plan), SIREHNA has developed, for the French Ministry of Defence (DGA/SPNuM), a demonstrator of an Automatic Decking System (ADS) of VTOL UAV on naval platforms. This three years development was composed of progressive test phases, based on numerical simulations and on physical experiments which ended by decking demonstrations of a real VTOL UAV on a physical simulator representing the motions of a decking platform of a frigate in severe sea conditions.

After a brief presentation of SIREHNA, this paper describes the objectives of the ADS, its principle, its functions and the hardware components of the system. The various test phases and the physical simulators used for these tests are also presented. The paper is ended by a summary of the decking results obtained and by a discussion on the future developments of the demonstrator to obtain an operational system.

2.0 PRESENTATION OF SIREHNA

SIREHNA is among the best European specialists for mastering the dynamic behaviour of ships and other objects. The company proposes a very complete panel of:

- *Products* (embedded systems / unmanned surface vehicles):
  - **Embedded systems:**
    - Ship monitoring, strains/motions (French Navy ships for helicopter and amphibious operations (BPC) “Mistral” and “Tonnerre”)
    - Dynamic positioning EasyDP-100
    - Multi-actuators stabilisation (rudder roll, mobile mass,…)
  - **Unmanned Surface Vehicles:**
    - USV platforms and specific navigation modules (mission planning, collision avoidance, wave management, station keeping)
    - Decking of UAVs
    - Unmanned vehicles recovery
- *Industrial applied RTD service* (Inertial/GPS, optical, hybridisation, measurements,…):
  - **Numerical simulation and Optimisation** : fluid mechanics, structural analysis, heat transfer, acoustics…In this field, SIREHNA stands out, for the resolution of coupled problems, with an approach based on multi objective parametric optimisation (modeFRONTIER software).

- **Measurements, experiments**: vehicle motions (ships, ground vehicles, …), « ground » measurement (waves, road, …), wakes (airplane, ship …). SIREHNA masters different measurement technologies, such as inertial, GPS, optical (PIV 2D-3D)…, and performs experiments in its own laboratory, in Customer laboratory and in the field.
- **Dynamic control**, platform stabilisation, auto pilot, dynamic positioning, UAV decking, active trajectory control.

➢ *Naval Architecture* by its subsidiary company BE MAURIC (n Marseille and Nantes):

SIREHNA's subsidiary, "Bureau d'Etudes MAURIC", has been drawing and designing for several decades superb ships from 20 to 100 m. They are mainly professional civilian or navy ships.

Recent realisations: BSP Alizé, buoy mooring vessels « Armorique » and « Hauts de France » (Socarenam), « FSIV » (SURF, Piriou).

Ongoing projects: 40 m Customs patrol vessel (Socarenam).

3.0 OBJECTIVES OF THE AUTOMATIC DECKING SYSTEM

The Automatic Decking System (ADS) aims at bringing the UAV, without operator remote control, on the ship landing platform, in severe sea state conditions (sea state 5, that is wave crest to trough height up to 7 m and platform vertical motion amplitude up to ±5 m). Within the project scope, the ADS role stops at touchdown and does not manage the after touchdown phase (UAV quick fastening and switching off).

4.0 DESCRIPTION OF THE SYSTEM

The ADS is mainly composed of a Landing Sensor (LS), which delivers in real time an accurate UAV position relative to the landing platform centre, and of a Decking Strategy (DS) module which uses the LS measurements, information on relative wind speed and direction on the deck and prediction of the platform motions to generate an approach trajectory and guide the UAV until touchdown. The main functions and components of the ADS are represented on Figure 1.

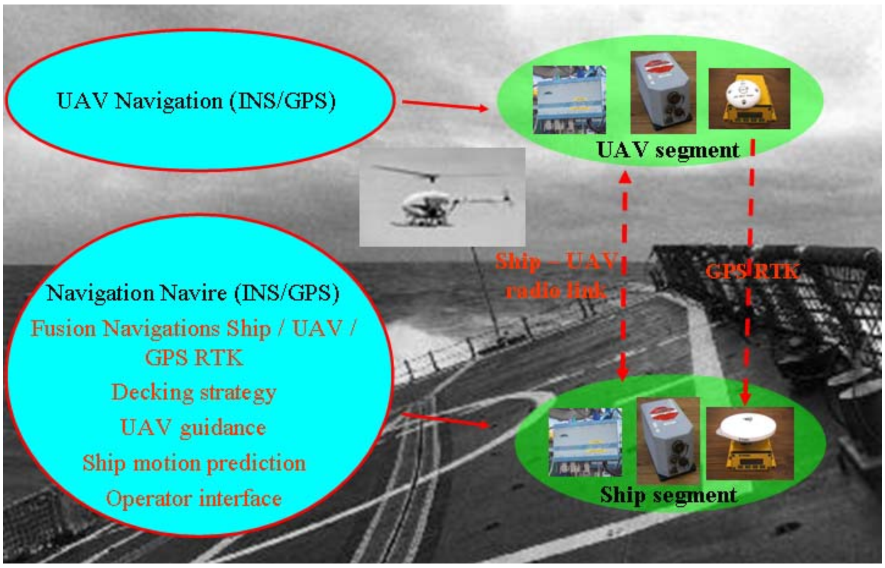

Figure 1: ADS main functions and components

- The Decking Sensor is composed of airborne and shipborne segments, connected by by radio link.. It measures continuously (10 Hz rate) and accurately (accuracy required better than 10 cm rms) the position of one reference point on the UAV (landing gear) with respect to the landing platform centre.. It also delivers the UAV navigation solution (heading, attitude, velocity) and the landing platform motions. These measurements are obtained by real time hybridization between inertial data (Fiber Optic Gyroscope Inertial Measurement Unit) and GPS data (absolute GPS and relative kinematic GPS between the UAV and the platform) performed both on the UAV and the ship.

- The Decking Strategy software module is hosted by the shipborne Decking Sensor computer. It allows:

  - Defining the optimal landing platform centre position for touchdown and associated time (touchdown just before the platform is up). In this purpose, a real time short term ship motion prediction method, based on motions measured by the shipborne DS segment, has been implemented.

  - Defining the approach trajectory and the UAV velocity profile along it depending on the position and time of the target touchdown point and on the airflow around the ship expected given the ship course and current environmental conditions. The trajectory and the velocity orders are regularly updated during the approach until touchdown, based on ship motion prediction and UAV measured position updates (closed loop UAV control).

  - Monitoring continuously the DS proper functioning, the UAV behaviour, verifying that orders to be sent to the UAV are consistent with its dynamic capabilities and, if not, generating alarms which automatically lead to a partial withdrawal (UAV sent back to the beginning of the final decking phase) or to a total withdrawal (UAV sent back to the beginning of the approach), depending on the alarm..

  - Transmitting in real time to the UAV ground control station guiding orders to reach the touchdown point.

5.0 TESTS OF THE SYSTEM

5.1 Tests description

Progressive test phases have been conducted all along the demonstrator development:

– Numerical simulations by means of a complete simulation platform developed in Matlab/Simulink environment (see Figure 2). This platform integrates the different functional modules of the ADS. It also integrates a ship motion simulation module and a module simulating the UAV response to guiding orders. In a first step, a very simple UAV response model has been used. In the final test phase with a real UAV, the response model of the Yamaha R-MAX UAV, developed and delivered by Onera, has been plugged into the simulator which has been further used to verify the R-MAX decking capabilities for the selected decking scenarios. In the future, this numerical simulator will also allow verifying the decking capabilities of other UAVs, provided that their response models are available.

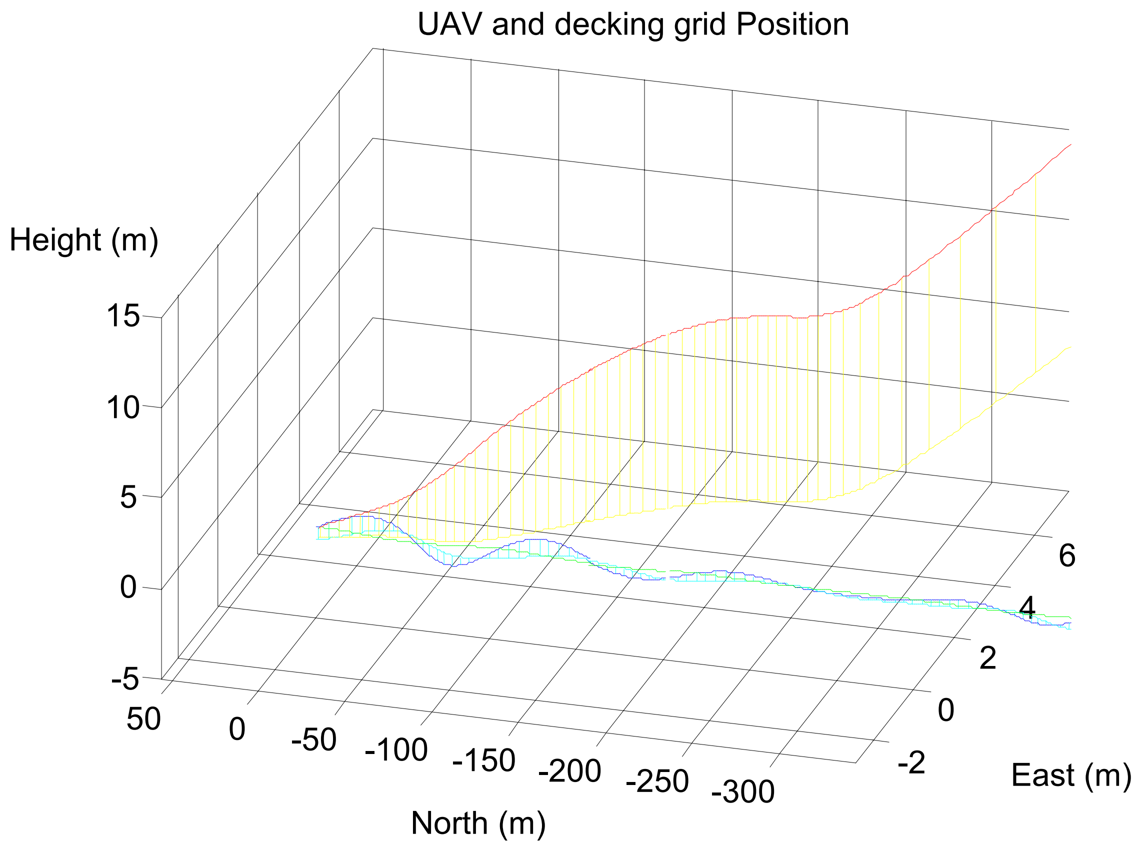

Figure 2 : Numerical decking simulation
(in blue: instantaneous position of the decking platform centre, in red: UAV reference point position, in green: horizontal track of the UAV)

– Decking Sensor tests by means of an experimental setup allowing verifying the DS measurement accuracy in dynamic conditions. This setup consists in mounting the two DS segments on the same support (thus keeping a constant distance between them) which is then subject to a superimposition of roll, pitch, yaw, heave motions and horizontal displacement (support installed on a roll/pitch generator mounted on a trailer; see Figure 3). The value and variation of the relative position vector module, measured by the DS, give then estimates of its dynamic accuracy.

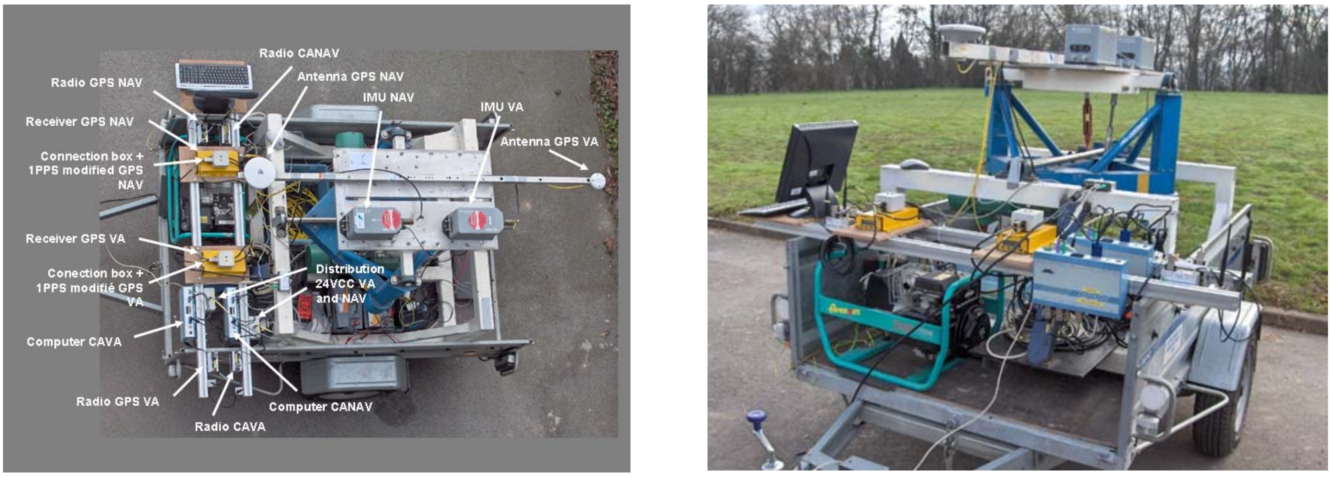

Figure 3: Decking Sensor dynamic performance tests

– Hardware-in-the-loop simulations in order to make first functioning verifications after implementation of the ADS modules on the real time computers, by inserting radio links in the loop and by simulating the sensor outputs.

– Physical simulations, at scale 1/4, of the final decking phase by means of two physical simulators: UAV and landing platform simulators (see §5.2 and Figure 4).

Figure 4: ADS testsat scale 1/4 on physical simulators
(outdoor tests; on the left: physical simulators of the platform (left) and UAV (right), on the right: ADS and simulators command consoles)

– Full scale physical simulations, by mounting the airborne segment on a real UAV (Yamaha R-MAX owned by Onera – Toulouse; see Figure 5), and by having the UAV decking on the platform physical simulator developed previously (see §5.2). The tests on the real UAV have been performed by generating various realistic platform motions corresponding to the motions of a non stabilized frigate calculated for sea state 5 and three wave angles (head waves, bow quartering waves and following waves), and for a smaller sea state in head waves.

Figure 5: Tests with a real UAV; integration of the shipborne segment on the R-MAX RESSAC UAV of Onera

5.2 Physical simulators

The principle adopted for the decking platform physical simulator is to simulate the displacements of a virtual platform materialised by two laser sheets. The two laser sheets are generated from a pan and tilt unit (PTU) and crosses each other at a fixed adjustable distance (lever arm). The PTU is mounted on the carriage of a motorised rail. The three translations of the platform are thus generated by controlling the two PTU rotations and the longitudinal translation of the PTU along the rail (see Figure 6).

The decking platform physical simulator has been used for 1/4 scaled tests, together with the UAV physical simulator, and for full scale tests with the real UAV. The platform motions to be generated are pre-calculated and uploaded on the computer which controls the platform simulator.

The UAV physical platform uses the same principle and hardware components (PTU and motorised rail), but only one point is materialised, by two laser beams crossing each other. The UAV physical simulator has been used for 1/4 scaled tests only but also provides a spare simulator for full scale tests.

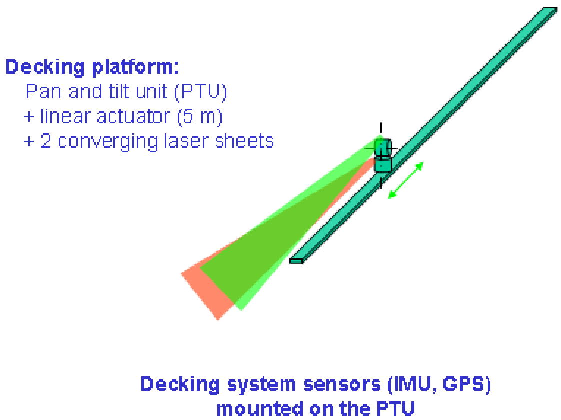

Figure 6 – Decking platform physical simulator principle

This original concept presents three major advantages:

- The simulators are compact and can be easily transported (on a road trailer) and deployable on any site, in particular on an aerodrome for testing with a UAV.

- There is no solid contact between the UAV and the platform at touchdown. In particular, for testing with a real UAV, the latter can cross the laser-based platform without any damage risk.

- The problem of managing the after touchdown phase (quick UAV fastening on the platform) does not need to be accurately accounted for: the UAV control is simply sent back to its ground station (the UAV is first maintained in hovering condition before having it going back to the starting point of the approach trajectory for a new decking for instance), as soon as the ADS informs the ground station that touchdown has occurred.

With this physical simulator, it is thus possible to « miss » deckings without damage, allowing looking for the limits of the UAV flight domain and for the ADS decking performances.

The DS sensors are mounted on the PTU and so are subject to motions corresponding to a certain point of the virtual solid. Thanks to the DS technology used (Inertial/GPS hybridization), the position measurements can be transported in any point of the virtual solid. Therefore the laser based platform motions can be derived from the sensor measurements by accounting for the lever arm corresponding to the decking platform centre (and corresponding to the intersection between the two laser sheets).

The rail and the PTU integrating their own position sensors, their instantaneous positions can also be recorded by the computer which controls their motions, giving the possibility to check, by post-processing, the actual motions generated, and, for 1/4 scaled tests with the two simulators, to check the DS relative position measurement accuracy.

In day light, the laser sheets are hardly visible, but all position measurements are recorded and processed, which allows monitoring the decking in real time and detailed post-processing and analysis in order to calculate the values of the decking criteria at touchdown. (horizontal and vertical relative speeds, distance to the platform centre).

During tests on a real UAV, the virtual platform is vertically shifted in order to allow sufficient time to take hand on the UAV if needed and thus ensuring the safety of tests. Two means for vertically shifting the platform have been used:

- Platform simulator located on the ground and vertical shift of the GPS measurement of the vertical position of the platform and of the vertical component of the relative vector of the platform with respect to the UAV; this solution allows testing with a large vertical shift (20 m for instance) hence a total safety for the first decking tests.

- Platform simulator mounted on a lifting platform. This solutions does not allow as large vertical shift as the previous solution (7 m on Figure 7), but allows mounting a camera on the platform simulator, in addition to the laser sheet generators, and performing decking in the alignment of the laser sheets, which strengthens the demonstrative features of the tests (see. Figure 8).

Figure 7: Tests on a real UAV with the decking platform physical simulator (simulator located at 7 m above the ground; laser sheets not visible in day light)

Figure 8 – Decking views recorded by the camera onboard the platform physical simulator (a representation of the platform position and width is inserted in images)

6.0 RESULTS AND PERSPECTIVES

Decking tests with a real UAV have been performed by generating various realistic naval platform motions, corresponding to the motions of a frigate calculated for a sea state 5 (wave height crest to trough reaching 7 m and platform vertical motions amplitude reaching ±5 m) and three wave angles (head waves, bow quartering waves and following waves), and a smaller sea state on head waves.

For each test, the Decking Sensor recordings have been analysed in order to calculate the values of the decking criteria at touchdown (distance to the platform centre, vertical and horizontal relative velocities) and to compare them with the limits of the technical specifications.

Many deckings, more than 40 over two days of tests, could be performed. They clearly demonstrated the capability to have successful deckings in almost all tested navigation conditions up to sea state 5. Unsuccessful deckings are encountered essentially for ship motions corresponding to navigation conditions to be avoided: sea state 5, bow quartering waves and non stabilised ship. In these conditions, the decking platform motions are very irregular, so difficult to predict, and have large sway and heave amplitudes, which means potentially large relative velocities in case of timing error.

The results obtained show that improving motion prediction will improve the decking performance in severe sea state while releasing the constraints on the aviation route to be followed by the ship and on the UAV dynamic capacities.

Other actions should also contribute to improving the decking capability in operation:

- Use of new navigation guidance tools (Operative Guidance Systems) which provide the helmsman with recommendations on the aviation route (ship heading and speed) to be followed to reduce the ship motions in the encountered environmental conditions.

- Specific active control of the naval platform (adaptation of its course keeping and stabilisation systems) coordinated with the Automatic Decking System so that the ship and the UAV “do not make more than one”.

The evolutions envisaged at very short term concern the improvement of the motion prediction method, and also the improvement of the robustness of the Landing Sensor (relative kinematic GPS robustness, hybridization with additional sensors) and of radio links. The demonstration of UAV decking on a moving solid platform (trailer, naval platform) is also envisaged in the next future.

7.0 ACKNOWLEDGMENT

We acknowledge the support of French Ministry of Defence and DGA/SPNum (Department of tactical missiles) to perform the described work.