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ON THE TRACK OF THE TIGER

(The Navigation System for the Tiger Missions)

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(The Navigation System for the Tiger Missions)

by

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11.1 SUMMARY

This paper describes the autonomous navigation system developed by Sextant Avionique for the PAH2/HAC, HAP Tiger Helicopter Program.

The Tiger Navigation System (TNS) is a complete and redundant system realized in cooperation with Teldix and MBB Dynamics.

It includes two strapdown inertial units with a 3 axis ring laser-gyro, two air data units, two strapdown magnetometers, a Doppler velocity sensor, a radar-altimeter and an option for a P-code GPS receiver. The hybridization of all these sensors permits to provide, with a high degree of accuracy, reliability and safety, the parameters required for the piloting, the displays and the guidance of the helicopter and its weapon system.

The development of the TNS has begun in December 1989 on the selection of the Sextant - Teldix - MBB proposal by Eurocopter after a phase of intense competition. Two complete systems with their test equipment were delivered end 1991 for the Eurocopter bench tests, and also the first flight system with spare units in April 1992.

This papers presents the TNS architecture and functions and describes the design of the main units.

11.2 INTRODUCTION

The role of the Tiger helicopter includes anti-tank (PAH2/HAC), support-protection and anti-helicopter (HAP) missions, during day and night, and the most part of time, at NOE (Nap Of the Earth) flight level and in hostile environment.

This very short mission portrait permits to identify the main requirements on the Tiger Navigation System (TNS) as expressed in the RFP (Request For Proposal) issued by Eurocopter in 1988 :

- autonomous and accurate,
- robust and designed for military environment,

- reliable and safe in flight,
- easy to use by the crew and to maintain on ground,
- light weight,
- of course, at low cost of ownership.

The answer of Sextant Avionique and its partners Teldix and MBB to these requirements was to propose and to develop :

- a modern and second-generation navigation system based on :
  - . a very compact Strapdown Computer (SDC) using a 3 axis small size RLG and miniature accelerometers,
  - . light weight Doppler Velocity Sensor (DVS), Radar-Altimeter (RA) and GPS receiver, using high electronics integration and full digital processing,
  - . modular architecture, extensive use of VLSI (32 bit microprocessors, ASIC's and hybrid components), and choice of Ada software for the master unit (SDC),
- improved functional concepts for performance and safety, based on :
  - . inertial / air data / Doppler hybridization techniques,
  - . automatic in-flight magnetic calibration,
  - . all domain air data, including low airspeed,
  - . integration of GPS,
  - . segregation between high integrity AHRS (Attitude and Heading Reference System) and high performance navigation functions,
  - . powerful BIT (Built-In Test) at various levels : sensor/device, peripheral unit, master unit (SDC) and sub-system (cross-monitoring of critical data between the two independent chains).

Thus the combination of high grade sensors with performent algorithms allows Sextant Avionique and its partners to guarantee to Eurocopter attitude, heading and navigation accuracies significantly better than the ones specified in the RFP (these were typically 0.5° for attitude and 2 % of distance or 300 m / 15 min for navigation).

11.3 TNS SYSTEM APPROACH

11.3.1 A redundant system architecture

The figure 1 presents a block-diagram of the TNS architecture.

The TNS consists of two identical duplex channels, each one composed of :

- one Strapdown Navigation Computer (SDC), from Sextant Avionique with a participation of Teldix,
- one Pressure and Temperature Measurement Unit (PTMU) with its associated Temperature Probe (TP), from Sextant Avionique,
- one Magnetic Sensor (MS), from Sextant Avionique,

Futhermore, each channel uses measurements from two simplex common sensors :

- one Doppler Velocity Sensor (DVS), from Teldix,
- one Radar Altimeter (RA), from MBB Dynamics.

The DVS measures the helicopter ground speed along the aircraft axes. The RA provides height above ground.

The MS is a 3 axis strapdown magnetometer that measures magnetic field components along the aircraft axes.

The PTMU includes two pressure sensors and provides impact temperature, static and dynamic pressures.

All those sensor measurements are used by the SDC's to elaborate AHRS and navigation information which are distributed to user systems via various interfaces.

In addition, the TNS uses AFCS (Automatic FLight Control System) actuator information to compute airspeed parameters in the Low Air Speed (LAS) domain.

On Tiger helicopter, the SDC's are installed in separated avionics bays (for vulnerability), the PTMU's in the nose near the pressure and temperature probes, the MS's in the rear part of the cabin, while the DVS and RA are mounted under the cabin, their antenna part being outside.

The actual total mass of the TNS is 24.1 kg, including the two SDC mounting trays, while the mass specified in the RFP was 27 kg target / 30 kg maximum

Each SDC provides the following interfaces with the avionics system :

- MIL STD 1553B redundant data bus,
- 2 Arinc 429 outputs to AFCS1 and AFCS2, for flight control data transmission,
- 1 Arinc 429 input / output spare,
- A Gilham encoding interface to IFF transponder,
- 4 Program-pins inputs (SDC position, HAP/HAC helicopter, etc...),
- 2 Clear Control inputs (from pilot and gunner), that are direct commands for "clearing" mission sensible information inside SDC.

The TNS uses the 1553B bus to support its data exchanges with CDUs (Control and Display Unit), MFDs (Multi-Function Display), AFCS and EUROMEP.

In particular, the TNS (which does not include any dedicated control panel) receives initialization and control commands from CDU or MFD via the 1553B bus.

In addition, two other direct communications exist :

- a "low altitude warning" signal generated by the RA to the ECAS (Electronic Crew Alerting System) sub-system,
- communication with ECM (Electronic Counter-Measures). The TNS disposes of two "silent modes" under the control of the crew :

  . if required for detectability, it can stop the transmission of DVS and RA. In this "mute mode", AHRS function remains available but not, of course, localization and radio-height,
  . for radar warning operation, DVS and RA can stop periodically their transmission (intermittent silence every 500 ms). For this purpose, the DVS transmits a silence command signal that synchronizes the operation of ECM and RA. This intermittent mode doesn't affect the functioning and the performance of the TNS.

Inside the TNS, the communications between the two SDC's and the DVS, RA and PTMU's, are realized by digital Arinc 429 links.

Provisions exist for interfacing each SDC with a GPS receiver for coupling purpose.

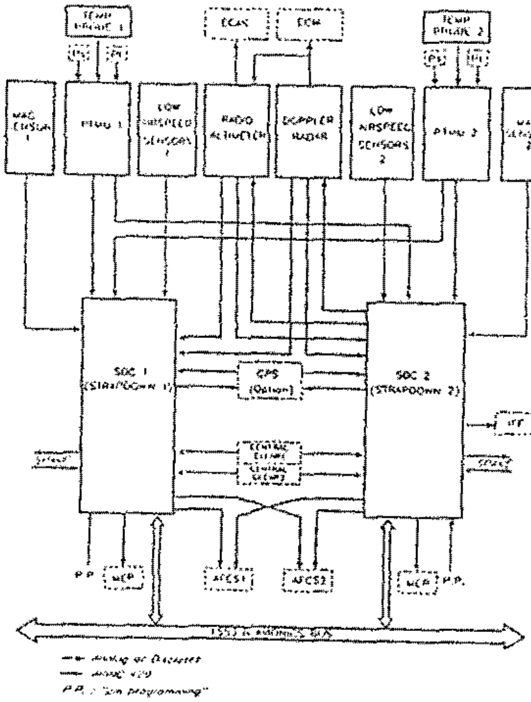

FIGURE 1 - TNS PHYSICAL ARCHITECTURE

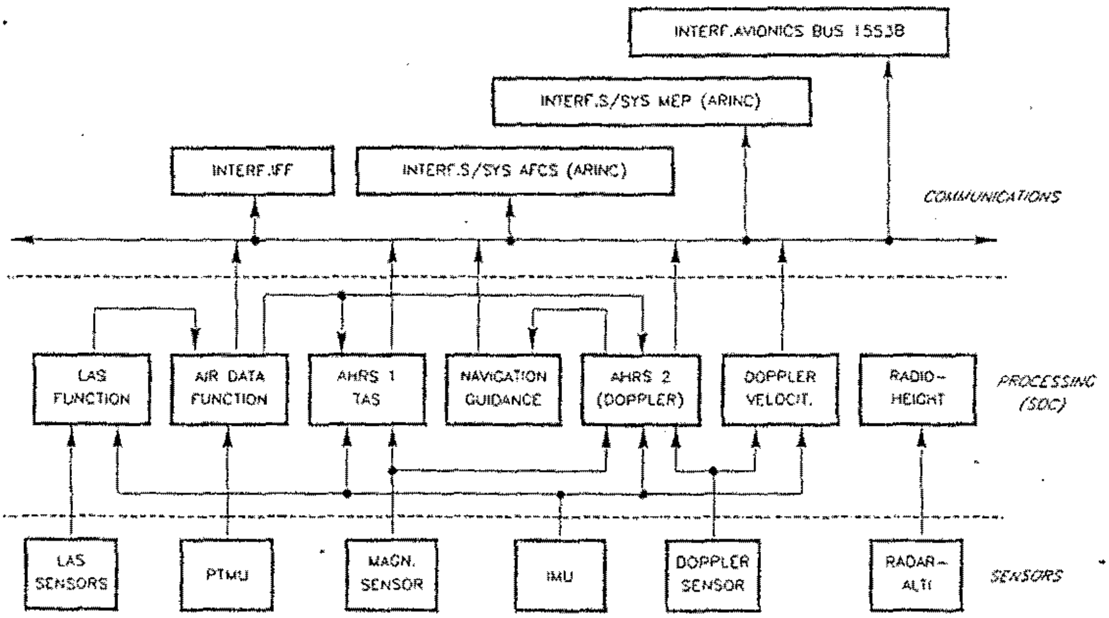

FIGURE 2 - TNS FUNCTIONAL ARCHITECTURE

11.3.2 Two-level functional architecture

The architecture solution specified by Eurocopter for the RFP integrates in fact two functional levels :

- the "Primary References" level, destined to the basic modes of AFCS and displays for the stabilization and the piloting of the vehicle, and characterized by a high level of integrity. This level corresonds to the elaboration of attitude, heading, air data and vehicle dynamics,
- the "Mission" level, destined to the upper modes of AFCS and to the mission equipment (weapon system, ECM, etc...), and characterized by a high level of performance and availability.

From this analysis, Sextant Avionique has decided to implement inside the SDC two independent AHRS "platforms", each computed by a dedicated processor :

- the basic platform (AHRS1), hybridized with the airspeed that is a safe and available information,
- the mission platform (AHRS2), hybridized with the Doppler, that provides the best performance for the navigation.

The figure 2 presents the TNS functional architecture.

The main functions processed by the SDC are the following :

- AHRS1,
- ARHS2,
- helicopter references computation (angular rates, acceleration, ground velocities, ground height),
- air data computation (IAS, TAS, Zb, Vz, etc...),
- localization (present position computation),
- BIT (pre-flight, background and maintainance tests),
- cross-monitoring with the second SDC,
- guidance (To, From-To, Route),
- present position updating,
- magnetometer calibration,
- LAS calibration,
- directional gyro (with manual heading updating possibility),
- way-point coordinates conversion :
  - geographic - UTM,
  - relative - absolute coordinates.

The following sections detail some specific functions of the TNS.

11.3.3 Automatic magnetic calibration

Though this operation is very rare (new helicopter or major vehicle repair changing its magnetic signature), it is important for the users.

The TNS is provided with a function of in-flight automatic calibration of the magnetic perturbations caused by the helicopter.

This patended procedure has been used by Sextant Avionique for 12 years for navigation and magnetic anomaly detection applications.

The operational advantages are to avoid the irksome "8 heading" magnetic compensation on ground, to provide a better compensation quality (compensation with the in-flight configuration) and to have a continuous monitoring of the helicopter magnetic status by an "off-line" compensation process run as a background task.

For the TNS, Sextant Avionique has developed a "second generation" calibration process that permits to compensate, with the identification of additional terms of the magnetic error model, the "magnetic" misalignment errors.

This improvement presents important additional advantages :

- improved performance for heading and consequently for navigation,
- no need for geometrical alignment between the SDC and the MS,
- taking into account of the possible in-flight structural deformations in the MS mounting area. Indeed, without this method, the structural deformations may cause an important heading error.

The TNS magnetic compensation is a totally autonomous procedure and is realized during a specific flight the duration of which is about 5 minutes.

The TNS indicates then to the crew the end of the procedure under the form of a status word on the databus.

The compensation models for the two MS are stored in both SDC's and also BCSG's. So, in case of replacement of one unit, the magnetic models can be reloaded easily via the databus.

11.3.4 <u>Low airspeed function</u>

It is wellknown that on helicopter, at low speed (i.e. under 20 m/s), the perturbations caused by the rotor flux make invalid the air data measured with classical pressure sensors.

To overcome this problem, the idea is to compute a synthetic airspeed by using information from flight control actuators (longitudinal cyclic, lateral cyclic, collective, antitorque pitches) and attitude information. This method provides longitudinal and also lateral components of airspeed.

The interest of LAS, that led Eurocopter to specify this function in the RFP, is triple :

- for the weapon system, the knowledge of airspeed vector allows to improve largely the efficiency of non-guided weapons (gun and rockets),
- at mission level, the knowledge of the wind allows to improve the load capacity in hover,
- for the piloting safety, the knowledge of the lateral airspeed component allows to respect the lateral flight limit, that is important in difficult flight conditions such as landing on ship or hovering during night with heavy sea.

With the support of the French MOD, Sextant Avionique has conducted a work program for 10 years in the LAS domain, including studies, simulations. This development, called CLASS (Crouzet Low Airspeed System), was the subject of two patents in 1984 and 1988. Four flight test series were conducted by the Flight Test Center of Brétigny, France, respectively in 1984, 1985/86, 1988/89 and 1991/92, totalizing about 70 flight hours.

The results of the last flight test series have permitted to confirm the announced performances and to optimize the LAS function for the TNS, in particular :

- an improved automatic LAS calibration, deemed by the flight test pilots as satisfactory for the piloting,
- LAS algorithms not affected by the mass and the centering of the helicopter.

The procedure for the LAS calibration and the storage inside the SDC's of the resulting model is the same as for the magnetic calibration. The circunstances needing the LAS calibration are also the same.

11.3.5 GPS option for the TNS

The section describes the GPS option proposed by Sextant Avionique in the frame of the TNS.

The GPS is recognized by everyone as a very interesting complement for the TNS for the following reasons :

- precise positioning (30 m for P-code), usable for updating the position elaborated by the TNS,
- precise ground velocities, better than those issued from the DVS,
- redundancy of ground velocities, allowing the integrity check of this information used by AFCS,
- redundancy of navigation : a precise navigation based on SDC-GPS may be replaced by the basic SDC-DVS one in case of loss of GPS reception.

The architecture recommended by Sextant Avionique for integrating a GPS with the TNS consists to connect a stand-alone GPS receiver with both SDC via Arinc 429 links and a synchronization line for SDC-GPS coupling (see figure 1).

The advantages of this solution are :

- possibility to dispose of PVT (Position, Velocity, Time) information independently of the SDC,
- possibility to use a standard GPS receiver, not necessarly redunded,
- minimization of developments.

The GPS receiver proposed for the TNS in cooperation with a German company, is a version of the Sextant Avionique NSS 100 P the characteristics of which are given in figures 3 and 4.

11.4 TNS UNIT TECHNOLOGIES

11.4.1 Inertial Strapdown Unit (STRATUS)

The STRATUS is a very compact inertial strapdown unit especialy designed to fulfil all the Tiger requirements, and realizing the functions of inertial sensors, computation of the double platform and the navigation, and data communication inside the TNS and with the Tiger avionics system.

Its size corresponds to a Arinc 600 3MCU (320 X 194 X 90 mm, i.e. 5.5 liters) and its mass is lower than 5.9 kg.

For STRATUS, Sextant Avionique has chosen the Ring Laser Gyro (RLG) technology and especialy the 3-axis gyro called PIXYZ in order to fulfil the requirements of performance, reliability, ruggedness, small size and low cost.

Briefly, on the PIXYZ, there are three 14 cm perimeter square cavities, orthogonally arranged within a single vitro-ceramic block. Six mirrors are placed on the octahedron thus obtained : each mirror being common to two of the cavities. The assembly thus obtained operates as three lasergyros, the axes of which form an undeformable trihedron that is dithered by a single device around its trisector axis.

In addition to the basic advantages of RLG (performance, mechanical unsensitivity, reliability and high dynamics), the PIXYZ solution decreases almost by a factor of 2 the following : weight, size, power consumption and cost.

The PIXYZ has flown in 1991 at the French Flight Test Center (9 flights) with a "'host" AHRS and navigation system and has demonstrated excellent performances, largely compatible with the needs of TNS.

The figures 5 and 6 present views of STRATUS architecture and sub-assemblies.

STRATUS unit includes six sub-assemblies or SRU's (Shop Replacable Unit) :

- the rigid structure equiped with the PIXYZ, 3 miniature accelerometers, a motherboard and EMI/NEMP protection devices,
- the high power voltage for the RLG,
- the sensor processing board,
- the "AHRS" processor board,
- the "SYSTEM" processor board,
- the low voltage power supply board.

The "SYSTEM" software is written in ADA, while the "AHRS" one is keeped in Assembler for optimization purpose. All the STRATUS software was developed according to the DOD 2167A standard, with the highest level of criticality (level 1).

11.4.2 DVS 1.0 Doppler Velocity Sensor

The DVS 1.0 DVS, selected for the TNS, is supplied by Teldix GmbH under a licence of CMC Montréal, Canada. The basic product is the CMA-2012 DVS, selected also for the US LHX program.

The DVS 1.0 is a new development, single LRU Doppler Velocity Sensor designed for application on helicopters and fixed-wing aircraft. Drawing on CMC's extensive experience with the design and development of Doppler Radar systems and related technologies, the design parameters of the DVS 1.0 were set to achieve significant reduction in size, weight, and cost over current systems, while maintaining or enhancing performance capabilities, and improving reliability.

In order to reach these characteristics, the DVS 1.0 incorporates innovative design features, including a new lightweight printed circuit radome/radiating structure, and state-of-the-art signal processing and packaging techniques.

The DVS 1.0 retains the proven Frequency Modulated, Continuous Wave (FM/CW) modulation technique and a four-beam Janus configuration with sequentially radiated beams. FM/CW modulation provides the following proven benefits over CW and Pulsed CW transmission methods :

- greater insensitivity to precipitation and sea spray,
- excellent rejection of near reflections (aircraft structures, sling loads, etc...),
- better hover performance through elimination of carrier noise breakthrough (leak), thus yielding a very low hover velocity threshold,
- excellent performance over all speed/altitude ranges, with predictable altitude performance resulting from modulation frequency selection,
- insensitive to shipborne radars.

The figure 7 gives a view of the DVS 1.0.
The main characteristics of the DVS 1.0 are the following :

- mass : 5.3 kg,
- size : 373 X 345 X 49.5 mm (6.4 liters),
- MTBF : 12000 hours (in helicopter environment),
- performance : see hereafter.

Since 1989, the DVS 1.0 has been flight tested on various aircraft, in particular :

- in 1990, on Bell 206 helicopter,
- mid 1991, on two helicopters of US Special Operations Command (CH-47 and UH-60),
- beginning 1992, on Navajo aircraft.

All the flight results were as expected, in particular with excellent behaviour over water and in hover.

DVS 1-0 PERFORMANCE SUMMARY

	VELOCITY	ACCURACY
FORWARD Vx	- 90 TO + 450 km/h	0.30 % Vt + 0.1 m/s
LATERAL Vy	± 90 km/h	0.30 % Vt + 0.1 m/s
VERTICAL Vz	± 25 m/s	0.20 % Vt + 0.1 m/s

$Vt^2 = Vx^2 + Vy^1 + Vz^2$

- ATTITUDE VERSUS ALTITUDE AND TERRAIN

		ALTITUDE		
TERRAIN	ATTITUDE	3000M (10000 FT)	1000M (3000 FT)	150M (500 FT)
Land	Pitch	± 40 deg	± 60 deg	± 70 deg
	Roll	± 45 deg	± 65 deg	± 75 deg
Sea	Pitch	± 20 deg	± 40 deg	± 60 deg
(BFT-1)	Roll	± 25 deg	± 45 deg	± 65 deg

- OVER WATER ACCURACY MET TO BEAUFORT 1
- SOFT DEGRADATION TO BEAUFORT 0
- NO PERFORMANCE DEGRADATION IN MODERATE RAIN
- ACQUISITION 2 SECONDS MAX. (TYPICALLY LESS THAN 500 ms)

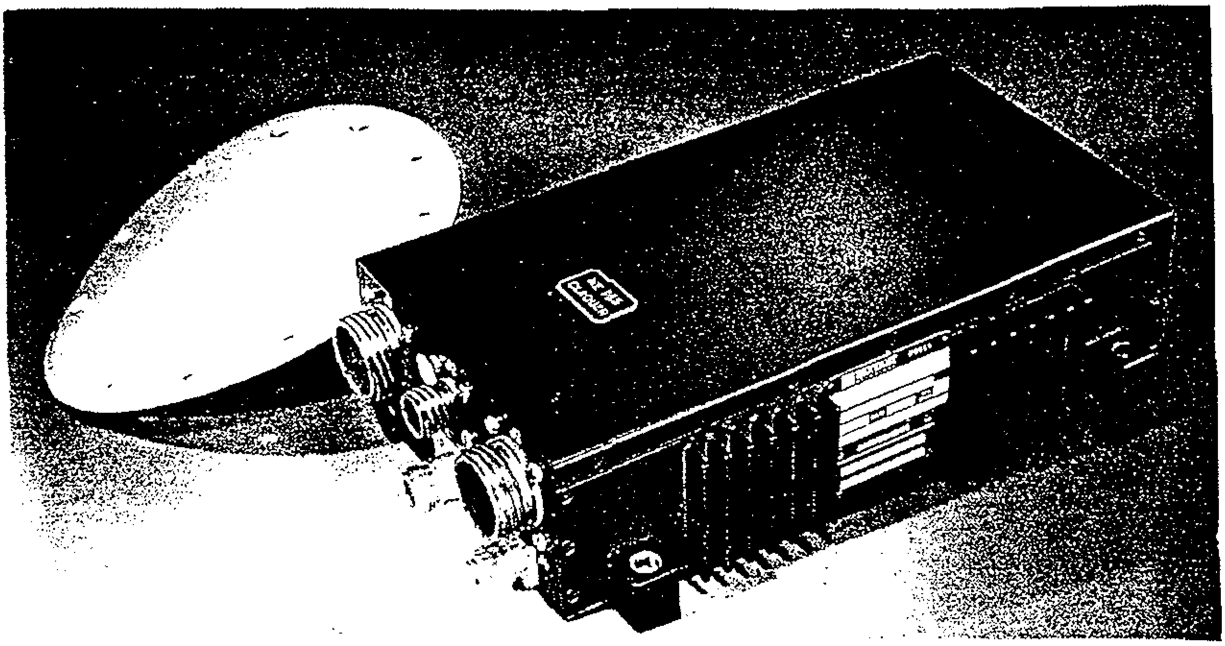

FIGURE 3 - VIEW OF THE NSS 100 P GPS RECEIVER

PERFORMANCE	According to STANAG 4294
. GPS signal	L1 and L2, P and C/A code
. Channels	5 parallel channels
Anti jamming	58 dB J/S
. Dynamic	1500 m/s, 12 g
. T T F F	< 60 s
. Horizontal position	18 m (2s)
. Altitude	28 m (2s)
. Ground speed	0.1 m/s
PHYSICAL	
Dimensions	RPU 130 x 240 x 63.5 mm
	AU ø 160 (F2)
. Weight	RPU 2.2 Kg
	AU 0.5 Kg
Consumption	28 VDC - 22 W
ENVIRONMENTAL	MIL STD 810

FIGURE 4 - MAIN CHARACTERISTICS OF NSS 100 P

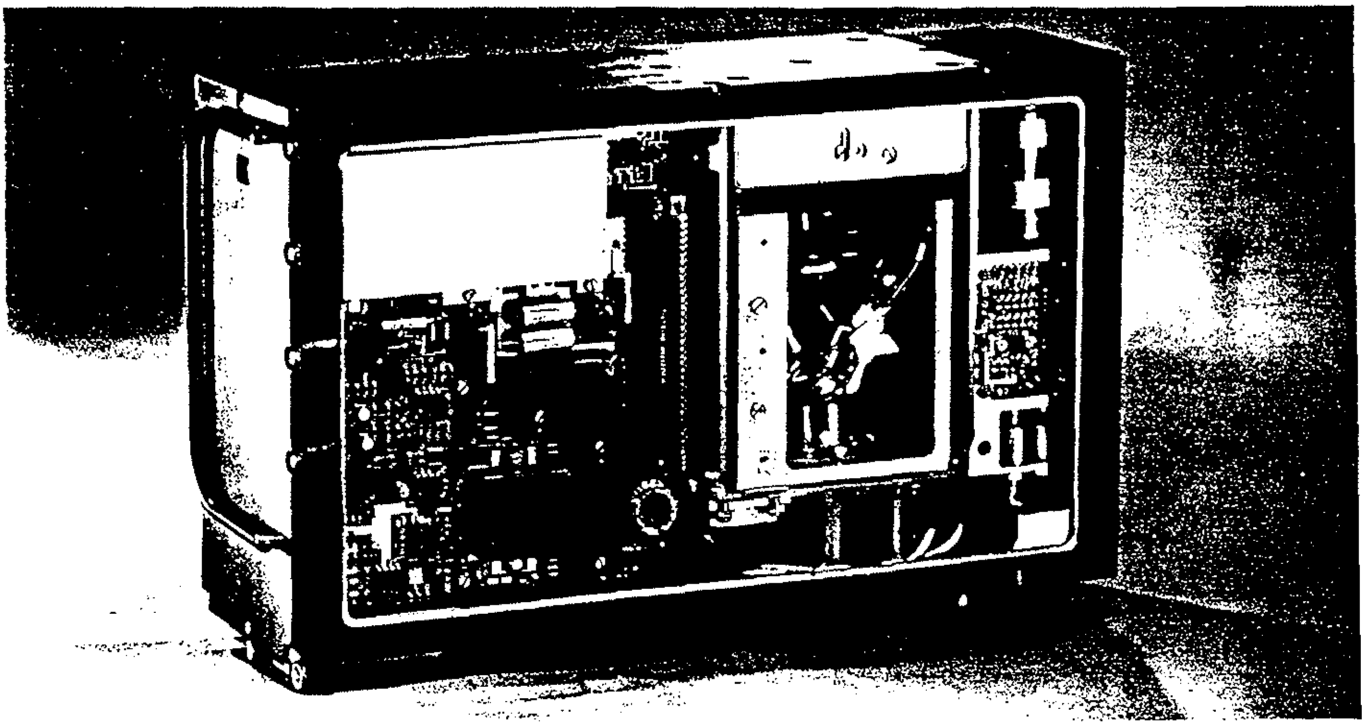

FIGURE 5 - STRATUS UNIT ARCHITECTURE

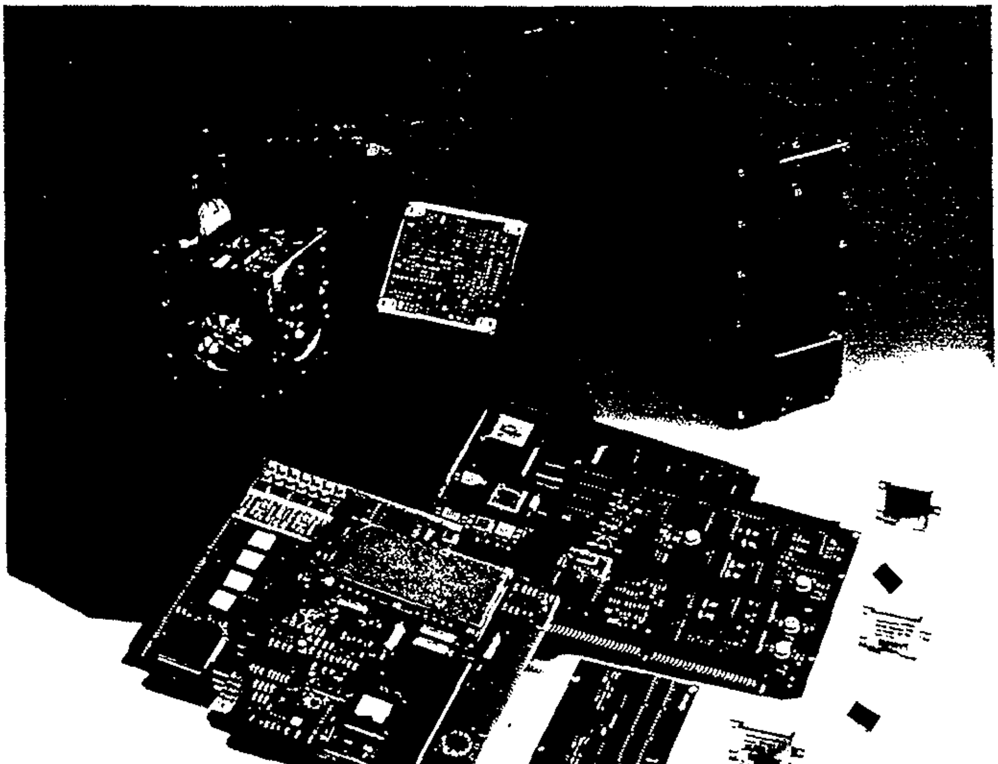

FIGURE 6 - STRATUS SUB-ASSEMBLIES

11.4.3 Radar - altimeter

The RA supplied by MBB Dynamics (Defence Group), Ottobrun, is derived from the unit selected as DWS 39 altimeter for the Gripen program.

Compared with previous RA generation, the RA of the TNS is a single integrated unit characterized by low weight, size and power.

This is achieved by using state-of-the-art technology :

- RF front end in Ga As MMIC,
- digital processing unit in CMOS technology, realizing powerful signal prcessing (FFT, waveform generation, integrated selftest and ECCM capabilities).

The RA has been tested successfully in 1990 and 1991 on aircraft (Pilatus) and helicopter (BO 105).

The figure 8 gives a view of the RA. The main characteristics of the RA are presented hereunder :

Transmitter Power	70 mW max. with power management
Height over ground range	0 - 750 m
Accuracy	± 0.63 m or ± 2 % actual height, whichever is the higher value (for > 95 % error detection rate)
Update rate	≥ 20 Hz
Maximum angle	Roll axis ± 45° Pitch axis ± 30°
ECCM	Measures to produce low detectability, jamming, and damage susceptibility, such as: - minimal transmit time - silent mode - jammer detection and receiver protection
Selftest	Integrated self test, diagnostic down to module level
Power Requirements	16 Watt max. at 28 VDC
Temperature Range	- 45°C to + 71°C
Dimensions including connector, antenna and mounting flange	69.8 mm X 228.2 mm X 148.2 mm
Weight	1.5 kg max.
MTBF	> 8000 hr
MTBD	> 7000 hr calculated as in MIL HBK-217

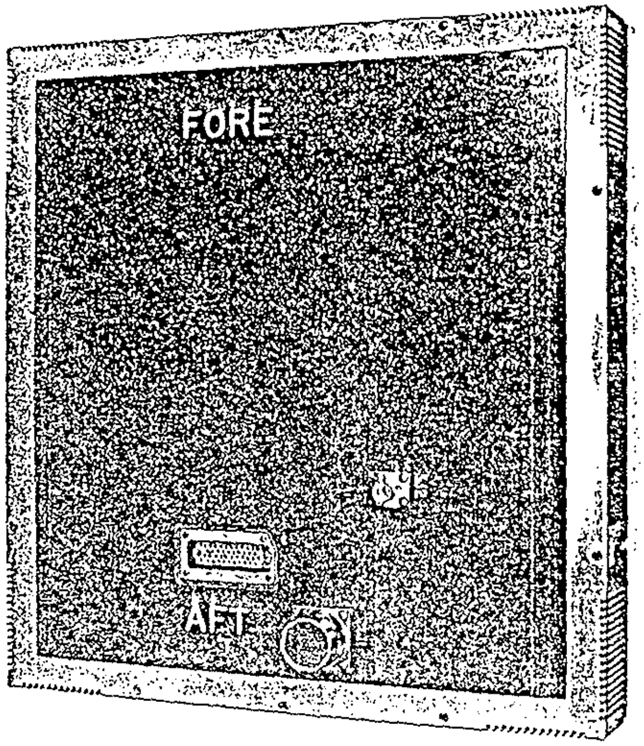

FIGURE 7 - VIEW OF THE DOPPLER VELOCITY SENSOR (DVS 1.0)

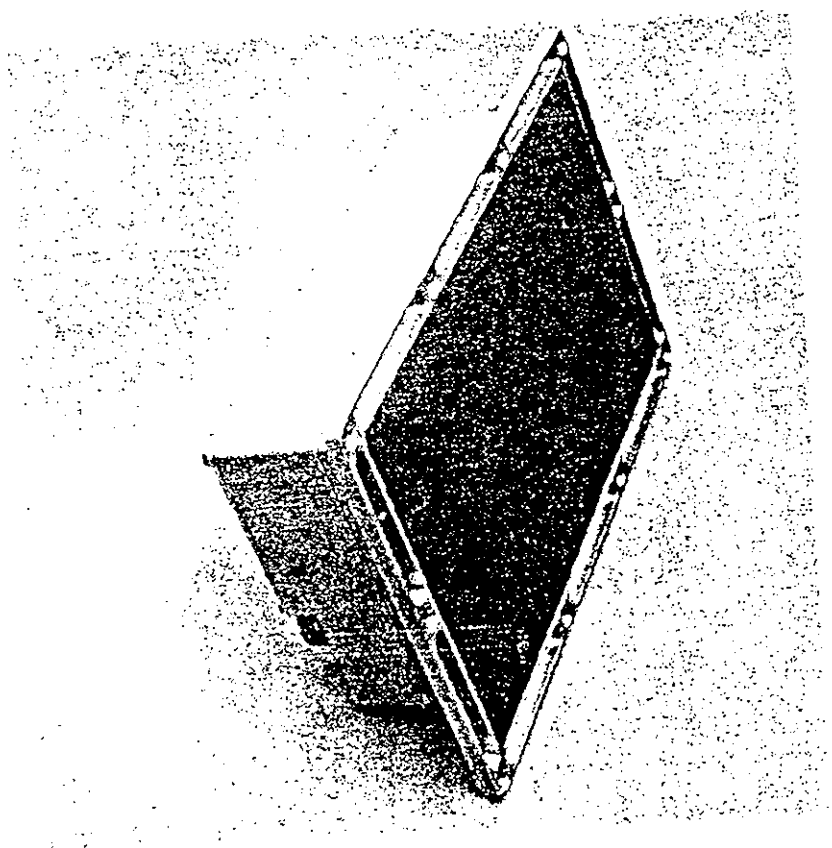

FIGURE 8 - VIEW OF THE RADAR-ALTIMETER

11.5 CONCLUSION

The autonomous navigation system developed by Sextant Avionique for the Tiger helicopter program is intended to enter in operation at the end of the century.

Designed from the experience of military helicopter navigation specialists combined with the most recent technologies, the Tiger Navigation System (TNS) offers the best suited solution to the requirements of a system for the year 2000 and beyond :

- minimum mass, size, and life cycle cost,
- high grade performance,
- large growth potential.

Moreover, by the means of a French-German deep and balanced cooperation, the TNS constitutes an unique opportunity to create the conditions of a long-term and enlarged partnership in the domain of navigation for helicopters.

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