

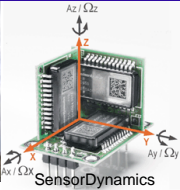
IMU & high performance inertial MEMS 2011

Complete review of inertial sensors market 2009-2015

Sample



Kongsberg



SensorDynamics



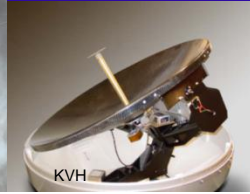
Airbus



InterSense



Boeing



KVH



Honeywell



US office secretary of defense



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Objectives of the report

- **In order to be exhaustive, the scope of this report covers:**
 - Gyroscope technologies: DTG, RLG, FOG, HRG, Quartz, MEMS
 - Accelerometer technologies: Electromechanical pendulous type, Piezo, MEMS
 - Level of performance: Industrial, tactical, inertial navigation and strategic grade
- **The objectives of this report are the followings:**
 - To provide market data on high performance Inertial Measurement Units and MEMS accelerometers / gyroscopes: key market metrics & dynamics
 - Unit shipments, revenues and average selling price
 - Market shares for each category of application
 - Industrial, tactical, inertial navigation and strategic grade sensors are taken into account
 - To provide application focus on key existing markets and most promising emerging ones
 - Architecture of the systems, functions that are used, new features and specification requirements
 - Insight about future technology trends & challenges
 - Pricing analysis and expected evolution
 - To provide a deep understanding of inertial sensor value chain, level of integration & players
 - Quasi-exhaustive list of sensor manufacturers worldwide with technology offer
 - List of key integrators worldwide
 - Analysis on the new players and potential new entrants with MEMS technology

Who Should be Interested in this Report?

- **High-performance accelerometers and gyroscope suppliers**
 - Understand the system level technology trends and requirements for each application
 - Evaluate market potential for your components depending on performance and technology
 - Understand the differentiated value of your products and technologies
 - Identify new business opportunities and partners
 - Monitor and benchmark your competitor's advancements
- **IMU module and AHRS or INS suppliers**
 - Evaluate the market potential of your product portfolio
 - Define diversification strategies on new applications
 - Find the best technologies to integrate and the best suppliers depending on your target markets
 - Identify new business opportunities and partners
 - Have an exhaustive analysis of the competition on a broad range of IMU field
- **MEMS material, equipment, or foundry / packaging service suppliers**
 - Identify new business opportunities and prospects
 - Understand the level of activity of your customers
 - Understand what are the applications that will drive the volumes in 2015
- **Integrators of inertial solutions (INS, AHRS, sensors...)**
 - Find the best technologies to integrate and the best suppliers depending on your target markets
 - Understand what will be the future applications to develop by taking benefit on the recent advances in inertial technologies
- **Financial & strategic investors**
 - Understand the structure and value chain of the high-end inertial industry
 - Estimate the potential of new devices such as tactical-grade MEMS gyroscopes...
 - Get the list of main key players and emerging start-ups of this industry worldwide

Companies cited in this Report

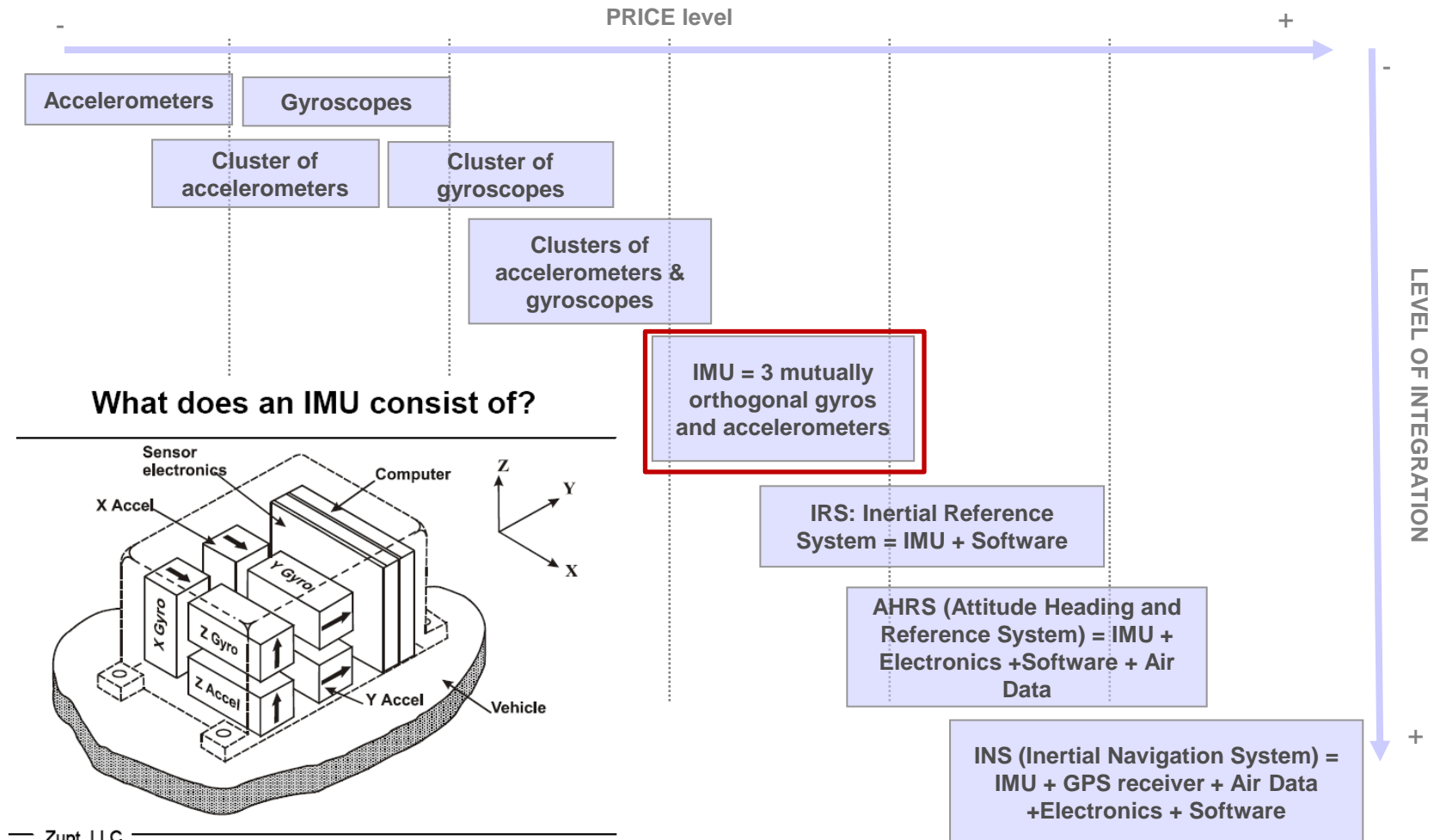


Agiltron, AIMS - Zetiq Development, Airbus & ATR, Al Cielo, American GNC, Analog Devices, Applanix, Ascension, ASM (Automation Sensorik Messtechnik), Astrium, Atlantic Inertial Systems, Autoflug, Azimuth, BAE, Beijing Aerospace, Boeing, Cape Peninsula University of Technology, CASC: China Aerospace, Clymer Tech, Cobham, Colibrys, Comac, Corrsys-Datron, Crossbow, CSRI Elektropribor, Daihen, Dassault Aviation, Denel, Diehl BGT Defence, Doosan DST, EADS Astrium, Elbit Elop, Elbit Systems, Endevco, Eurocopter, Expertisa, Fanuc, Finmecannica, Fitzoptika, Freescale, Fugro, Fuji, GE Energy, GEM elettronica, General Dynamics, Genesys, Georgia Tech, Gladiator technology, G-nius, Goodrich, Hindustan Aeronautics Limited (HAL) - Edgewood Technologies, Hitachi, Honeywell, Horiba, HP, Hyundai Rotem, IAI Tamam, IGI mbH, i-mar, IMEGO, Imperial College London, India Space Research Organization (ISRO), Inertial Science, Innalabs, InterSense, ION, ISNAV, Israel Aerospace Industries, Israel Military Industries, IXSEA, JAE - Japan Aviation Electronics Industry, John Deere, Kawasaki heavy industries, Kearfott, Kinematics Inc, Kionix, Kongsberg, KVH, L3 Communication, LITEF, Lockheed Martin, Loral, Lumedyne Technologies, Matra, MBDA, Melexis, Memsense, Michigan Aerospace Corp., Micro Infinity, Microbotics, MicroInfinity, MicroPilot, Microstrain, Movea, Nera Networks, Nexter, NG Italia – Lital, Northrop Grumman, NovAtel, Omni Instr., O-Navi, Onera, Optolink, Orbit Technology Group, PCB Piezo, Physical Logic, Poogsan FNS, Pruftechnik, Qinetiq, Rada, Rafael, Ramsys, Raytheon, Raytheon Anschütz, Rheinmetall, Rockwell Collins, Roketsan, RUAG, Saab, Sagem, Sandia National Laboratories, SBG Systems, Schlumberger, SDI: Seven Dimension Information Corp, Selex, Sensoror, SensorDynamics, Sensorex, SensR, Sercel, Sherbone Sensors, Silicon Audio, Silicon Design, Silicon Sensing Systems SSS, Southern Methodist University, Stockholm Precision Tools, Summit Instruments, Symphony Acoustics, Syowa Sokki, Systron Donner Industrial, Taiwan National Space Organization (NSPO), Teknol, Tethers Unlimited, Thales, Tokimec, Tronics, Vigor Technology, VTI, Watson Industries, Xi'an Chinastar, XSens, Yaskawa Electric, Yishay Sensors, and many others...

Introduction, definitions & methodology

Definition of an IMU

- In the following slides, IMU will be referred as the following device:



Introduction, definitions & methodology

Definition of inertial devices performance

- For comparison purpose main inertial devices parameter to be studied is inherent bias stability

- This is in-run drift or 1-y bias repeatability:
 - The error independent of inertial rate or acceleration
 - In μg or $^\circ/\text{h}$
- Tactical grade IMUs integrate gyroscopes with $0.1^\circ/\text{h}$ to $100^\circ/\text{h}$ bias stability

- Each application has also its specific requirements in term of:

- Size
- Power
- Weight
- Dynamic range
- Bandwidth
- Run to run drift
- Harsh environment compatibility
- Power consumption
- Certification
- Lifetime
- ...

Definition of application grades

Accelerometer long term Bias Repeatability	Gyroscope Bias Stability	Corresponding Grade
1g	$1^\circ/\text{s}$	Commercial Industrial Low end tactical
1g	$100^\circ/\text{h}$	
100mg	$10^\circ/\text{h}$	
10mg	$1^\circ/\text{h}$	Tactical
1mg	$0,1^\circ/\text{h}$	Inertial Navigation
100ug	$0,01^\circ/\text{h}$	
10 μg	$0,001^\circ/\text{h}$	
1 μg	$0,0001^\circ/\text{h}$	Strategic

Application Space for IMU & High Performance Inertial MEMS



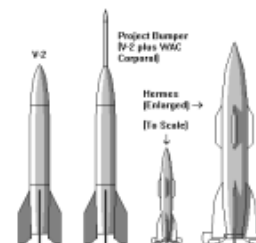
- Agriculture
- AUVs
- Freight transport ship
- Healthcare
- High speed train
- Inclinometers
- Oil drilling heads
- ROV
- Satcom antenna stab
- Stabilization of optical systems
- Survey instruments
- UGVs
- Vibration monitoring
- ...

Industrial, Commercial naval and Offshore

IMU & High Performance Inertial MEMS

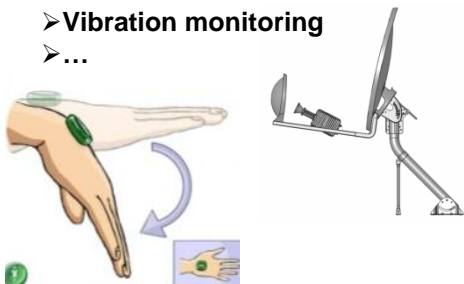
Commercial Aerospace

Defense



- Defense ships
- Defense transport aircraft
- Defense UAVs
- Guided munitions
- LAV/Artillery Guns
- MAV/Tanks
- Military & special mission helicopters
- Military fighters
- Military submarines
- Nuclear missiles
- Short, medium and long range missiles
- Soldier
- ...

- Business Jets
- Civil aircraft
- Civil helicopters
- Civil and paramilitary UAVs
- General aviation
- Satellites
- Spacecrafts & skyrockets
- ...



Executive Summary

Overview (1/3)

- **High performance motion sensing is gaining interest in many industries**
 - In the military & aerospace areas, the use of Inertial Measurement Units (IMUs) and other systems based on high-performance gyroscopes has been widespread for navigation, flight control or stabilization functions for decades
 - Today we now see many industrial and healthcare applications emerging, driven by the possibility to integrate new functionality at low cost, mostly thanks to the recent developments in MEMS accelerometer and gyroscope technology
- **The market for IMUs is estimated to be \$1.55B in 2009, dominated by defense and aerospace applications**
 - Yole sees this market growing at a 9% annual growth rate, to reach \$2.60B in 2015
 - Industrial, commercial naval and offshore applications will be the most dynamic with 16.5% yearly growth, when the aerospace and defense markets will be limited to a 5.5% and 6.8% annual growth
- **Several technologies are currently on the market, RLG and FOG-based systems being the most widespread and still benefiting from progresses in photonics**
 - However the recent and rapid development of tactical-grade MEMS gyroscope technologies has the largest impact on the market landscape and on the competition
 - It is key for the companies involved in those markets to invest in the right technologies and partners, depending on the end-markets which are targeted
 - Different strategies are observed: some companies carefully invest in selected technologies like the market leader Honeywell, while others love all inertial technologies, like Northrop Grumman

Executive Summary

Overview (2/3)

- **MEMS industrial and tactical-grade type of sensors is the most dynamic technology**
 - Yole sees the market growing from \$361.8M in 2009 to \$604.6M in 2015 for single MEMS accelerometers and gyroscopes or assembly of MEMS accelerometers / gyroscopes
 - However many technical and commercial challenges are predicted for the players involved in MEMS: how to guarantee a high level of vacuum for keeping high performance over the years, how to bring down the costs when most of the applications are in the 100 or 1000 unit range per year, why is it so important to avoid export restrictions like ITAR, what are the best business partners to enter new markets which are sometimes captive...
- **The recent availability of tactical-grade MEMS IMUs is clearly attractive for a wide range of applications**
 - Indeed many applications will find interest in low-cost devices while it also opens new market opportunities such as precision guided munitions or small size UAVs
 - This explains why nearly each major IMU manufacturer has a MEMS technology today, although the status of developments is not the same for all players

Executive Summary

Overview (3/3)

- **This report is more than a simple update of the “IMU market 2007-2012” report**
 - **The involvement of Yole Développement on the high-end inertial market has continued to grow in the last couple of years, with discussions with key companies involved in the field all over the world and participation in many conferences**
 - **Although this market remains very complex to monitor, with a wide range of technologies, applications and players, Yole has been able to make a few modifications since the last version to be closer to the reality when it comes to IMU prices, penetration, number of systems in each vehicle, and market shares**
 - **Moreover a complete analysis of the impact of MEMS technology and on the geographic description of the market (including the dynamic Asian and Israeli markets) has been included**
 - **Yole also had the chance to have Mike Perlmutter, who has more than 30 years of experience in the inertial navigation industry, provide an important contribution to this report**

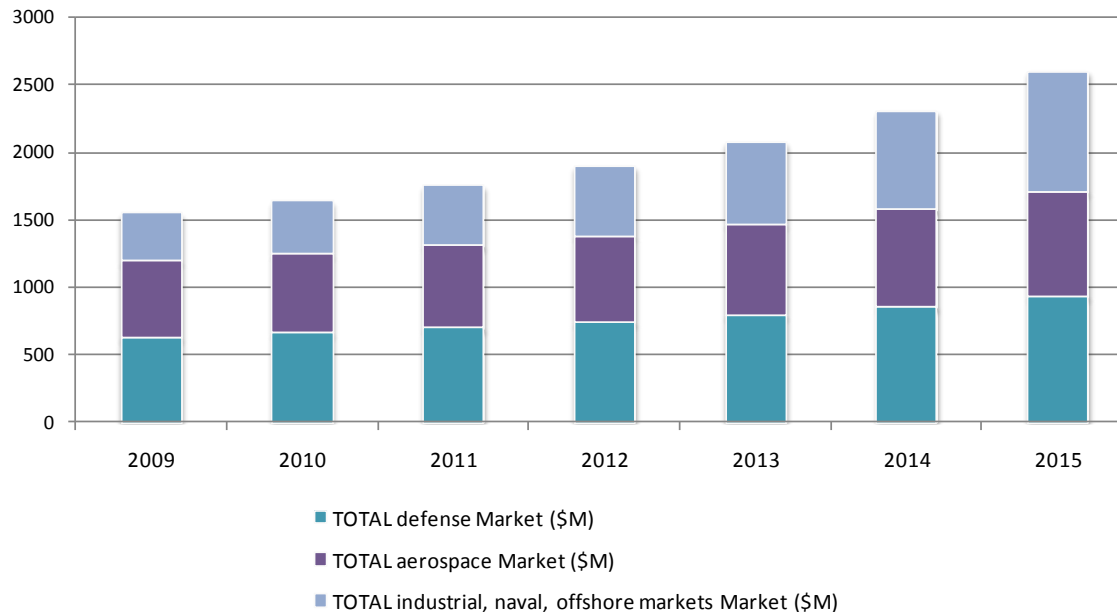
Executive summary

Global IMU market

- High-performance IMU market is a \$1.55B market in 2009
 - This market is expected to reach \$2.60B in 2015!
- In volume, this is a 190k units market in 2009, growing to 650k units in 2015!
- Defense and aerospace applications dominate the market
- Industrial applications are significant today and are expected to be the most growing markets until 2015
 - Most of the volume is expected to come from industrial applications but with lower cost sensors
 - Defense market is doing some interesting volume with ammunition applications mainly
 - Aerospace market is mostly low volume high added value markets

2009-2015 global market for high-performance IMUs

- Breakdown by field in value (\$M) -



EXAMPLE OF THE ANALYSIS FOR ONE APPLICATION: MILITARY HELICOPTERS

Defense IMU market

Military helicopter market

- **Highly equipped helicopters are divided in 2 categories:**
 - **Military helicopters: about 500 units each year**
 - **Helicopters dedicated to special missions: about 200 units each year**
 - For offshore applications, firemen...
 - Such helicopters have a level of electronics as high as defense helicopters: architecture similar to military versions
 - **Military rotorcraft market is growing at a constant rate**
 - The market is slightly growing that to some dynamic growing markets such as China
- **Military Market Overview**
 - **Combat Helicopters conduct battlefield observation and intelligence gathering missions for specialized units**
 - **Main manufacturers**
 - Bell Helicopter (USA)
 - Boeing (USA)
 - Sikorsky (USA)
 - Lockheed Martin (USA)
 - Eurocopter (Eur, EADS Group)
 - AgustaWestland (Eur)



Boeing AH-64 Apache



Defense IMU market

Military helicopter market

- **Military helicopters are often equipped with 2 Inertial Navigation Systems for redundancy purpose**
 - For 70% of those helicopters
 - 0.1 to 0,01°/h IMU are used
 - It is estimated that 30% of them have only AHRS systems for cockpit instrumentation purpose
 - More and more MEMS IMUs are used: lower accuracy is required
- **Stabilization features and condition monitoring use inertial sensors but do not require an IMU**
 - 2 assemblies of 2 gyroscopes each usually perform the stabilization features, to increase flight smoothness
 - 20 to 30 accelerometers for vibration and acceleration monitoring for the different parts (maintenance purpose)
 - The following parts are monitored: gear box, main rotor, cockpit, nose, blade...
 - Those accelerometers are not part of IMUs
- **Electronic commands require flight control assistance provided by inertial data separated from the INS**
 - Recent military rotorcraft demand very high dynamic flight capabilities
 - This function, which is using exclusively gyroscopes, only starts to be integrated on high-end platforms



Eurocopter NHI NH90

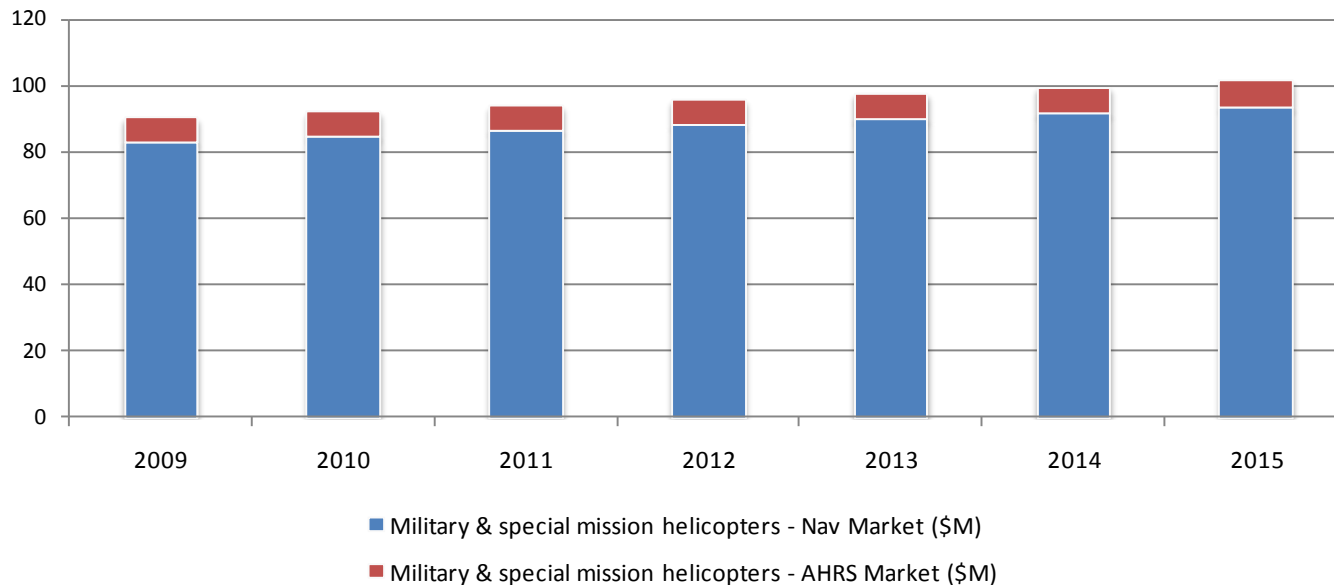
Defense IMU market

Military helicopter market

- **Most of the market for IMU is for INS**
 - AHRIS systems use lower price IMUs (\$15-20k compared to \$50-55k for navigation), giving a smaller market opportunity
 - Retrofit is also a large portion of the market

2009-2015 market for IMU in military and special mission helicopters

- In value (\$M) -



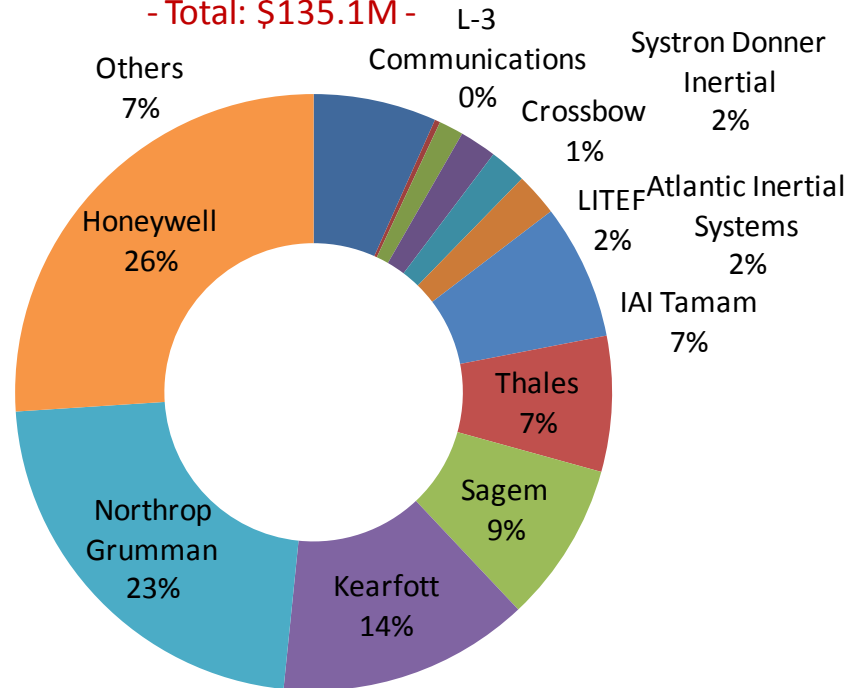
Defense IMU market

Military helicopter – Market shares

- Leading players are Honeywell, NG, Kearfott, Sagem, Thales and IAI Tamam

2009 market shares IMU in others defense avionics
 applications: UAVs, helicopters

- Total: \$135.1M -



About the Authors of this Report

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- **Contributor: Mike Perlmutter**

- Mike has worked in the inertial navigation field for over 30 years. He was director of strategy and planning at Northrop Grumman in 2007 when he retired from the company and established Skylight Navigation to consult in the area of inertial systems, navigation, corporate planning and strategy. Mike has published papers, chaired conference sessions, given talks and authored 10 US patents on inertial sensors, GPS and navigation technology.

