

SECTION 7 - GUIDANCE, NAVIGATION, AND VEHICLE CONTROL TECHNOLOGY

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SUMMARY

Overview (See Figure 7.0-1) This section encompasses technologies for both autonomous and cooperative positioning, coordination, and control of military force elements, as noted in the military S&T Plans. Included are technologies for flight management, guidance, and vehicle control. Elements of the technology continue to be improved and adapted to mission needs. This is especially true for the US Global Positioning System (GPS). Navigation is defined as obtaining the present condition or state of the vehicle from sensed values of position and motion. Guidance systems integrate these conditions and produce vehicle control responses. In essence, these technologies are closely coupled and overlap depending on application, which includes WMD. Most of these technologies have dual-use requirements, and all of them are essential for various mission needs. Commercial aircraft accuracy requirements are generally less than those for military aircraft. The trend is for consolidation of various navigation technologies into hybrid systems.

Rationale The militarily critical parameters key on values above which inertial, radio, and data-based referenced navigation equipment and vehicle control equipment could be used to deliver conventional weapons, a single item (for nuclear), individually targeted RVs, or a set of items to a level of accuracy appropriate to the destructive footprint of these munitions. **Accurate positioning, attitude, pointing, and control** of land, sea, air, and space vehicles are essential for effective coordination of highly mobile military forces. **Accurate time and frequency** form the basis for modern guidance, navigation, and vehicle control as well as telecommunication. These capabilities directly enhance the delivery accuracy and lethality of manned and unmanned,

guided and unguided weapons systems. In addition, other mission requirements, such as reconnaissance, require **accurate velocity, motion compensation**, and positioning synchronization data to maintain real-time knowledge of the enemy. Accurate position and time sequencing and use of sensor information are key force multipliers to offset numerical superiority of an adversary and reduce casualties. In the past few years, because of the application of dynamically unstable aircraft and missile design, the vehicle flight control systems (FCS) became vital to meet the design requirements of the platform. Similar advancements are being made in ground, marine, and spacecraft vehicle control. The long-term costs for Third World countries to design, fabricate, and apply this technology have been a limiting proliferation factor. This section contains important, highly leverageable technologies.

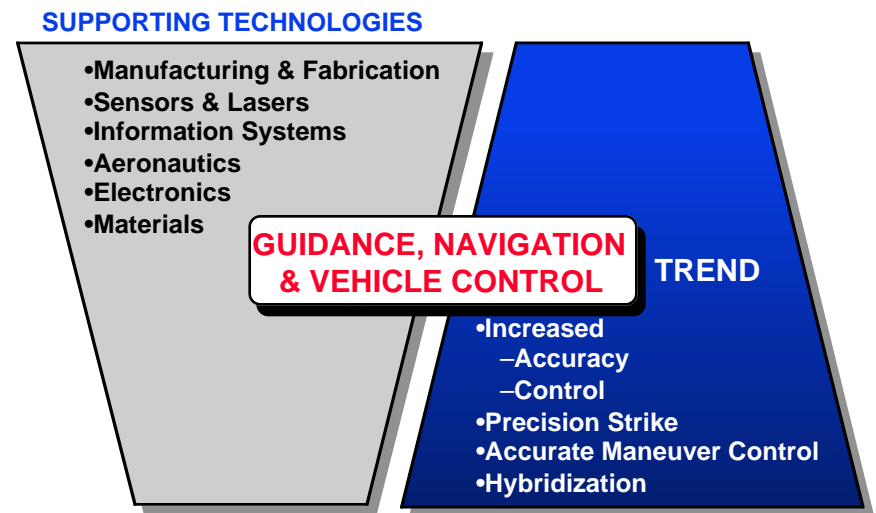


Figure 7.0-1. Guidance, Navigation and Vehicle Control Overview

Foreign Technology Assessment (See Figure 7.0-2) Depending on national desires and needs, nations have chosen to develop, produce, and use guidance, navigation, and vehicle control technologies for military and commercial purposes. Many countries do not have an indigenous aircraft manufacturing capability and the inherent flight control technology that are fundamental requirements. From a user viewpoint, inertial navigation systems are more expensive to produce and maintain than radio navigation systems. This fact and other military mission considerations have led many nations to rely more on radio navigation systems for many military and commercial needs. This fact is more evident now with the use of Global Navigation Satellite Systems (GNSS). The only worldwide radio navigation systems that exist are OMEGA, US GPS and the Russian Global Navigation Satellite System (GLONASS). Other regional radio navigation systems, such as LORAN C, have been produced to meet local needs. Some of the countries, such as France, the UK, and Russia, have been leaders in Guidance, Navigation, and Vehicle Control because of their indigenous aircraft industry. Much of the technology capability for many countries has been obtained through US licensing agreement transfers and foreign students attending US universities. US industry has depended on and supported US export control to obtain a level playing field for itself and foreign nations. US industry has also depended on the control regulations to be able to negate the offset demands for manufacturing data that are most often sought by foreign countries. **Foreign offset requirements** are one of the main proliferation mechanisms of these technologies. Further details of the foreign technology assessment are provided in the respective subsections.

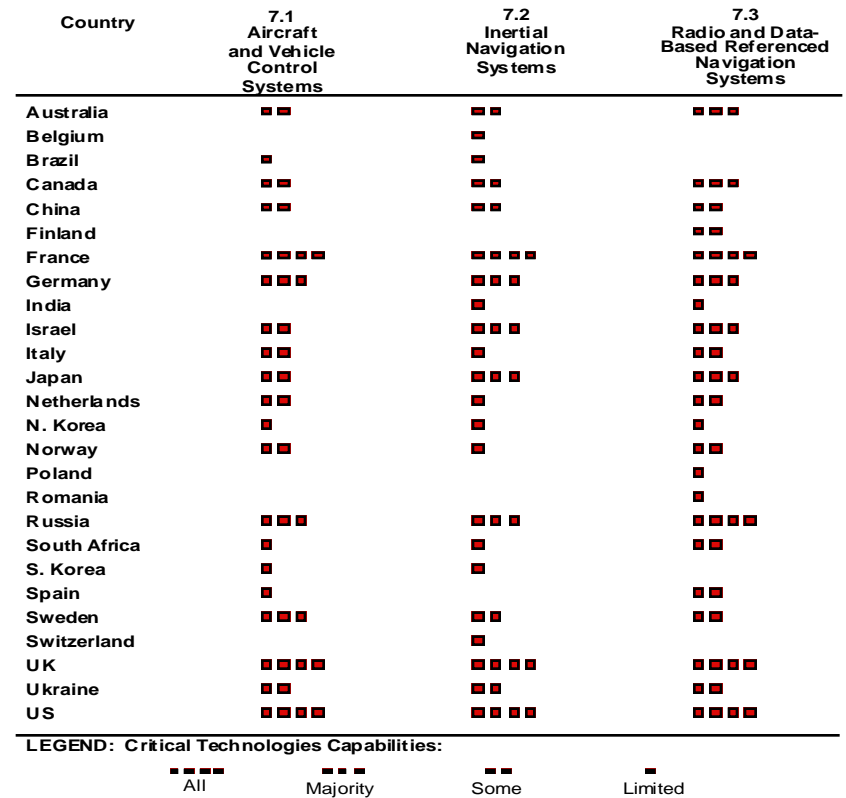


Figure 7.0-2. Guidance, Navigation and Vehicle Control FTA Summary

SECTION 7.1 AIRCRAFT AND VEHICLE CONTROL SYSTEMS

Overview (See Figure 7.1-1) Flight control systems (FCS) (including Fly-by-Wire and Fly-by-Light) are composed of sensors, computers, actuators, and the other system components dictated by the architecture, methodologies, and algorithms required by the air vehicle (aircraft, RPV, or cruise missile) to perform their intended missions. Similar control systems are used in ground, sea, and space vehicle missions. They function to control the vehicle, including agility and steering, to achieve the desired flight path (e.g., weapon launch windows). The FCS also prevents undesirable aircraft and missile motions or structural loads by autonomously processing outputs from multiple sensors and then providing necessary preventive commands to effect automatic control. Flight path optimization is an FCS procedure that minimizes deviations from a four-dimensional (space and time) desired trajectory based on maximizing performance or effectiveness for mission tasks. Particularly important are evolving adaptive control techniques for integrated control and signature control. Control actuators transform control logic into vehicle responses. New technologies are required to further reduce power and logistic support. Electric actuators are used in small civil aircraft, RPVs, and missiles. They replace conventional hydraulic, pneumatic, and mechanical drive systems in larger, high-performance civil and military aircraft and helicopters.

Rationale (See Table 7.1-1) National security considerations dictate a critical concern for FCS because of FCS use in weapon delivery platforms. The key characteristic of reliability in a wide variety of environmental conditions has caused FCS, in the past, to have had a high degree of autonomy relative to other components of the vehicle. With the advent of digital bus systems and redundant computers, the vehicle and FCS are being integrated with the other electronic and mechanical systems in the vehicle. Integration technology has, therefore, become a critical technology. Most, if not all, commercial practices evolve from military requirements with the g loadings and dynamics being considerably less for commercial use. Flight control laws and algorithms are the mathematical relationships defining input sensor processing, sensor selection, dynamic compensation, fault detection/isolation, and command generation to flight control force and moment generators and cockpit flight guidance displays. Control laws and algorithms are typically represented in the form of mathematical equations, block diagrams, flow charts, software source code,

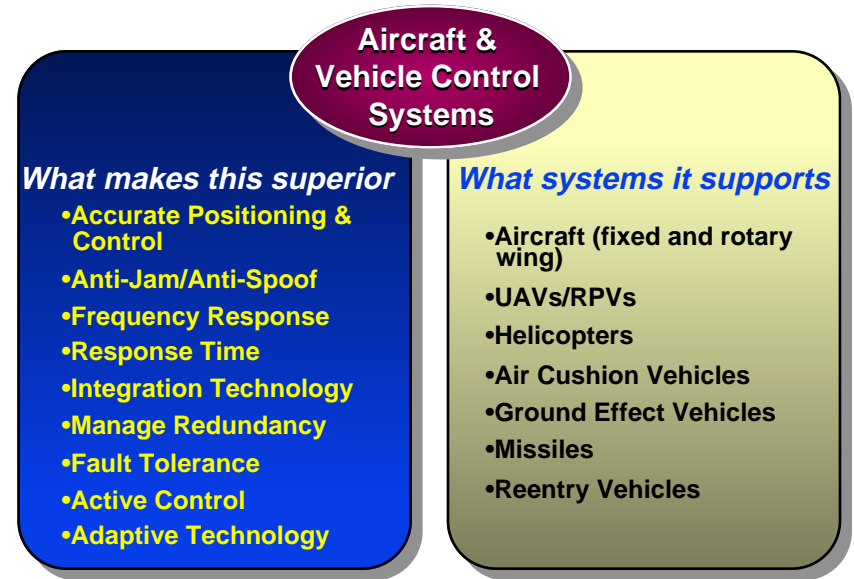


Figure 7.1-1. Aircraft and Vehicle Control Systems Overview

software design specification/program description language, logic diagrams, or circuit schematics. Description of flight control laws and algorithms in any of these forms are critical technologies if they contain any of the actual parameters (gains, time constraints, thresholds, limits) for military aircraft. FCS software in any embodiment (source, object, or machine code) associated with any military aircraft in operation or in development is critical. Reduction of aircraft signature by decreasing aircraft air data protrusions requires a knowledge of data processing and nonintrusive sensing.

Foreign Technology Assessment (See Figure 7.0-2) The US leads the world in vehicle FCS primarily because of software and CAD expertise. However, many countries, such as France, Russia, and the UK, now have autonomous capability in aircraft flight control, some of which has been adopted from a wide variety of US commercial and military aircraft.

Table 7.1-1. Aircraft and Vehicle Control Systems Militarily Critical Technology Parameters

TECHNOLOGY	MILITARILY CRITICAL PARAMETERS MINIMUM LEVEL TO ASSURE US SUPERIORITY	CRITICAL MATERIALS	UNIQUE TEST, PRODUCTION, AND INSPECTION EQUIPMENT	UNIQUE SOFTWARE AND PARAMETERS	EXPORT CONTROL REFERENCE
AIRFOILS, VARIABLE GEOMETRY	Fixed wing - external robustness to maximize L/D configured airfoil from supersonic only to include high subsonic region. Helicopter - Dynamically optimized airload distribution on rotors for 50% reduction in acoustic signature and 60% less vibration; Bandwidth of > 3 Hz	Smart materials	Digital air vehicle and control system dynamic computer models; CAD development software; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for linking design parameters to vehicle dynamic models.	Algorithms and verified data containing actual design parameters (e.g., response, shape, rates).	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
CONTROLLER, MULTI-AXIS	Cooper-Harper rating of < 3; No pilot induced oscillation (PIO) due to rate limiting	None identified	Digital air vehicle and control system dynamic computer models; CAD development software; pilot in-the-loop simulators; ground and flight testing of prototype systems.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits, thresholds).	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
ELECTRIC ACTUATORS	Output power > 4 hp; Rate > 50 deg/s; Acceleration > 100 inches/sec ² ; Bandwidth > 4 Hz	Rare earth magnets; see Materials	Digital air vehicle and control system dynamic computer models; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for developing power controllers.	Algorithms and verified data containing actual design parameters (e.g., power switching logic, gains, time constants).	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
FLIGHT CONTROL SYSTEMS, ACTIVE	30% reduction in pilot fatigue in 1–2 Hz region caused by turbulence induced structural oscillations; minimize flutter for aeroelasticity induced airspeed limits; 50% increase in structural fatigue life.	None identified	Air vehicle rigid, flexible and control system dynamic computer models; CAD development software; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for linking design parameters with flexible vehicle dynamics.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits) for military applications. Automatic verification and validation tools.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
FLIGHT CONTROL SYSTEMS, FULL AUTHORITY DIGITAL	Equivalent time delay of < 100 milliseconds; bandwidth of > 3 Hz; Aircraft loss rate per flight of < 1×10^{-5}	None identified	Digital air vehicle and control system dynamic computer models; CAD development software; pilot in-the-loop simulators; ground and flight testing of prototype systems.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits). Automatic verification and validation tools.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
FLIGHT CONTROL SYSTEMS, MULTI-DISCIPLINED INTEGRATED	Equivalent time delay of < 100 milliseconds; Bandwidth of > 3 Hz; Time to identify structural modes < time to double amplitude	None identified	Integrated air vehicle control system, structural and propulsion dynamic computer models; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for linking individual disciplinary models.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits). Automatic verification and validation tools.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7E
FLIGHT CONTROL SYSTEMS, RECONFIGURABLE	Detect and respond in less than the time to reach double amplitude	None identified	Digital air vehicle and control system dynamic computer models; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for linking individual disciplinary models.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits). Automatic verification and validation tools.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7D, E
FLIGHT CONTROL SYSTEMS, THRUST VECTORING	Equivalent time delay of < 100 milliseconds; Bandwidth of > 3 Hz; Rate limit > 60 deg/sec	None identified	Integrated air vehicle control system, structural and propulsion dynamic computer models; pilot in-the-loop simulators; ground and flight testing of prototype systems; CAD tools for linking propulsion and vehicle dynamic models.	Algorithms and verified data containing actual design parameters (e.g., gains, time constants, limits). Automatic verification and validation tools.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7D, E
NONCONVENTIONAL (OPTICAL/MODELING) AIR DATA SENSORS	Operation > 30,000 ft Covert Air Data with accuracy equivalent to conventional sensors	None identified	Unique computer models and laser velocimetry CAD Development Tools for linking algorithms and aircraft shapes	Compensation algorithms and verified data.	WA ML 10, 21, 22 WA Cat 7E USML VIII CCL Cat 7D, E

SECTION 7.2 INERTIAL NAVIGATION SYSTEMS AND RELATED COMPONENTS

Overview (See Figure 7.2-1) This technology area encompasses a wide range of systems and components that form the basis for autonomous, covert navigation and motion sensing. Included are Inertial Navigation Systems (INS), various types integrated systems, and each of many distinct types of gyroscopes and accelerometers that can be found in a navigation system. Multifunction inertial components are also noted. An INS is a self-contained system that provides continuous estimates of some or all components of vehicle state, such as position, velocity, acceleration, attitude, angular rate, and often guidance or steering inputs. An INS contains accelerometers and gyroscopes to sense linear and angular rate. It can be mechanized either as a gimballed platform or a strapdown inertial sensing unit employing a computer to provide the "software" equivalent of gimbals or a hybrid unit with either gimbal or strapdown features. Gyros and accelerometers can also be used as separate instruments. Separate militarily critical technology areas and parametric controls apply to gyros, accelerometers, and systems. (See Figures 7.2-2 and 7.2.3, which provide examples of applications.)

Rationale (See Table 7.2-1) This technology has been driven by military requirements. The reliability of ring laser gyros and fiber optic gyros has allowed for an expanding list of military and commercial applications. INS and their respective sensor components have wide applications in commercial transport and civil aircraft, surveying, research, and robotics. The GAO/NSIAD Report 93-67 of March 1993 noted, however, that "the technical data for nonmilitary INS is the same as for military INS and is particularly sensitive because it enables the licensee to manufacture all or part of the item." The INS and component parametric controls allow the export of INS for commercial aircraft while protecting the test equipment, software, and technology thereof. Export of INS and sensors is of extreme military concern and is specifically noted in the MTCR relative to its use for guidance and control. Military applications include strategic systems (missiles and RVs; strategic platforms); aircraft carriers, SSNs, and surface combatants; aircraft; tactical missiles; and land warfare. Targeting, surveillance, and command and control (C²) require high navigation accuracy. Low-speed vehicles employ INS navigation and attitude data for weapon direction and fire control. Commercial uses include launch vehicles, satellites, oil drilling platforms, directional drilling systems, dredging platforms, submersibles, hydrographic and natural resource survey vessels, ships, aircraft, automobiles, trucks, trains, and robotic production. Inertial navigation systems technology has been enhanced by advances in computer technology (memory capacity, throughput, and filters), sensor advancements, and electronics. However, levels of parametric controls that are traceable to critical and significant military capabilities have been developed.

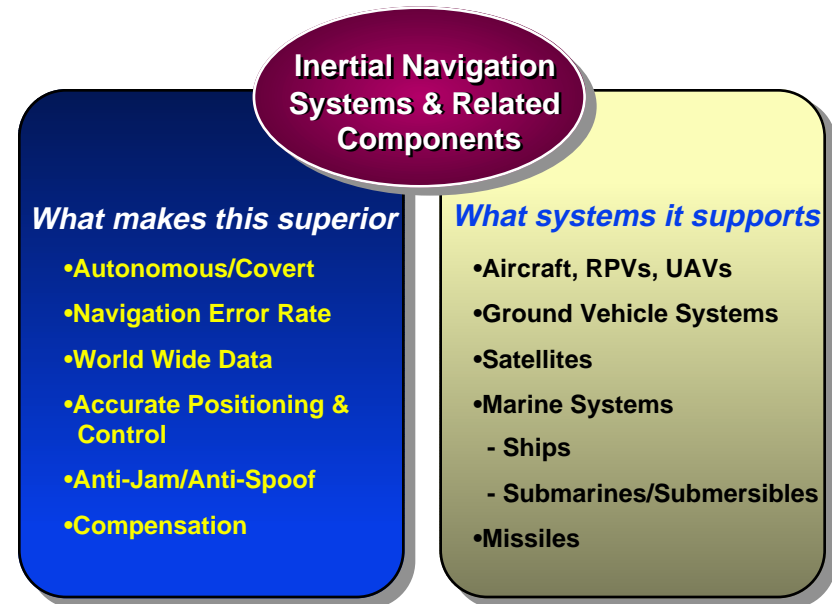


Figure 7.2-1. Inertial Navigation Systems and Related Components Overview

Foreign Technology Assessment (See Figure 7.0-2) The technology gap between the US and other nations is rapidly closing. The US leads the world in most inertial technology and is progressively improving in the areas of accuracy, alignment, size, weight, reliability, cost, and integration with digital processing technology. However, France, Israel, UK, PRC, and Russia are rapidly closing the gap. Russia and the PRC have produced conventional inertial products and have initial production capability in ring laser and fiber optic gyros. Russia has developed some flexure rotor and magnetically suspended gyroscopes, and the quality of these gyroscopes appears to be on a par with Western equipment. Since tuned rotor gyroscopes are inexpensive and very suitable for a space reentry guidance application, the acquisition of this type of technology has enhanced gyroscopic capability in maneuvering remote unmanned vehicles. Nations who are developing an inertial capability include Australia, Brazil, PRC, India, Israel, Italy, Sweden, South Africa, and Norway. Their major obstacles are access to a market of sufficient size to justify the development costs and the capital equipment costs for high-volume production. Italy, Brazil, and Sweden

have the capability to produce conventional spinning wheel inertial devices. Recent international conferences indicated a wide INS knowledge base in Russia and China. Russia produces both single-mode and multi-mode fibers, but the quality has not been ascertained. In Japan, the Ministry of International Trade and Industry has orchestrated the fiber optic industry as a critical industry of which fiber optic gyros are a small part of the market. The importance of fiber optic sensors to Japan is indicated by the fact that the Japan Research and Development Corporation has specific cognizance of this technology. Several

countries are now imbedding GPS receivers into their INS. The capabilities of the UK, France, and Japan are nearly equal to the US except for the most precise inertial systems and sensors. All these countries have pursued the evolution of inertial technology from spinning mass to floated gyro to dynamically tuned gyro to ring laser gyro and now to fiber optic gyros. Some have concentrated on only a few of these technologies. Germany, Japan, and Israel have developed fewer of these technologies than the US, UK, and France and have less total system integration experience.

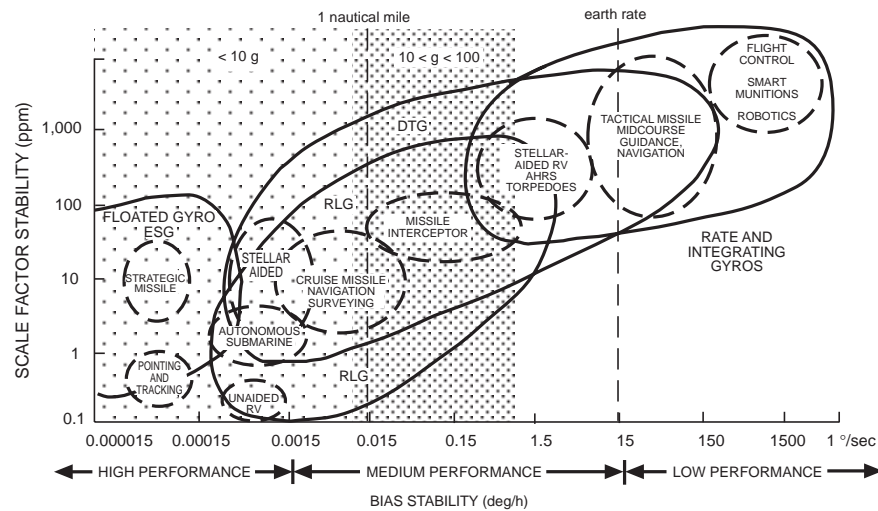


Figure 7.2-2. Gyro Technology Applications
(shaded area is militarily critical region)

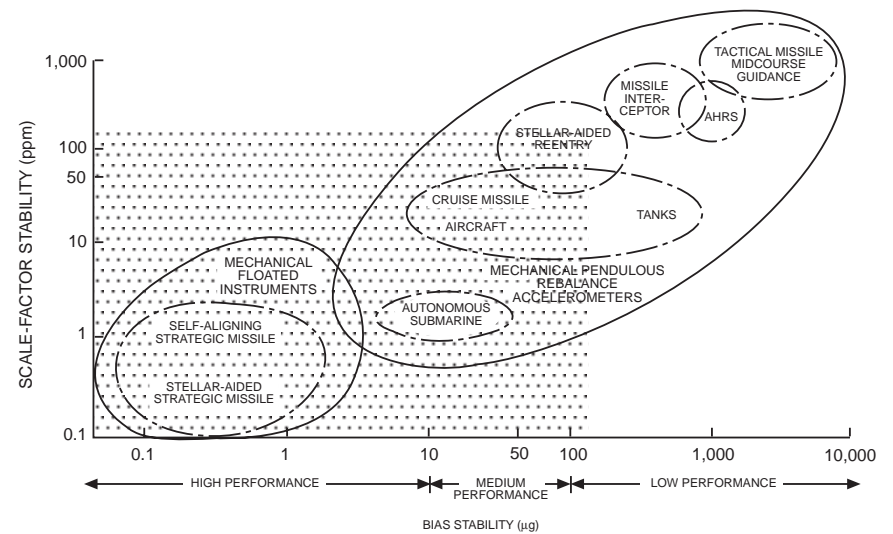


Figure 7.2-3. Accelerometer Technology Applications
(shaded area is militarily critical region)

Table 7.2-1. Inertial Navigation Systems and Related Components Militarily Critical Technology Parameters

TECHNOLOGY	MILITARILY CRITICAL PARAMETERS MINIMUM LEVEL TO ASSURE US SUPERIORITY	CRITICAL MATERIALS	UNIQUE TEST, PRODUCTION, AND INSPECTION EQUIPMENT	UNIQUE SOFTWARE AND PARAMETERS	EXPORT CONTROL REFERENCE
INERTIAL NAVIGATION SYSTEMS	For Aircraft, Vehicle or Spacecraft for attitude, guidance and control - Nav error < 0.8 nmi/hr 50% CEP For ships - Nav error of < 0.8 nmi in 3 hrs For missiles - Nav error of < 2 nmi/hr Or specified to function at linear acceleration > 10 g on any platform	None identified	Components require specially designed test, calibration, or alignment equipment Ships motion simulator CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. INS alignment time for moving platform and transfer alignment techniques	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
HYBRID NAVIGATION SYSTEMS	For A/C, Vehicle or Spacecraft - Nav error < 0.8 nm/hr 50% CEP For ships - Nav error of < 0.8 nmi in 3 hrs For missiles - Nav error of < 2 nmi/h Or specified to function at linear Acceleration > 10 g on any platform	None identified	Components require specially designed test, calibration, or alignment equipment. GNSS receivers require special simulator testing systems. CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Source code for combining INS with Doppler, GNSS or DBRN. INS initial align time for moving platform. Transfer align techniques and reference to geoid	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
INERTIAL/GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)	For A/C, Vehicle or Spacecraft - Nav error < 0.8 nm/hr 50% CEP Pointing accuracy < 75 arc sec For ships - Nav error of < 0.8 nmi in 3 hrs For missiles - Nav error of < 2 nmi/hr Or specified to function at linear acceleration > 10 g on any platform Signal decryption (anti spoof) and/or null-steerable antenna, jamming protection. Accuracy of < 20 meter 50% SEP in position and < 200 nanosecond in time. < 0.1 m/s velocity > 60,000 ft and > 1,000 kts	None identified	Components require specially designed test, calibration, or alignment equipment. GNSS receivers require special simulator testing systems. CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Source code for combining INS with GNSS. INS initial align time for moving platform. Transfer align techniques and reference to geoid	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
GYRO ASTRO TRACKING DEVICES	Azimuth accuracy < 75 arc seconds Or specified to function at linear acceleration >10 g on any platform	None identified	Components require specially designed test, calibration, or alignment equipment including clock accuracy of 1 microsecond/24 hrs Star signal simulators CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Source code for combining with INS. Transfer align techniques and reference to geoid	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
GYROSCOPES	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or specified to function at linear acceleration levels > 100 g on any platform See Figure 7.2-2	None identified	Gyro tuning test and dynamic balance station Gyro run-in motor test station Evacuation and fill stations Centrifuge fixtures for gyro bearings Scatterometers-accuracy > 10 ppm Profilometers-accuracy < 5 angstrom Fiber winding machines CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E

(cont'd)

Table 7.2-1. Inertial Navigation Systems and Related Components Militarily Critical Technology Parameters (Cont'd)

TECHNOLOGY	MILITARILY CRITICAL PARAMETERS MINIMUM LEVEL TO ASSURE US SUPERIORITY	CRITICAL MATERIALS	UNIQUE TEST, PRODUCTION, AND INSPECTION EQUIPMENT	UNIQUE SOFTWARE AND PARAMETERS	EXPORT CONTROL REFERENCE
ACCELEROMETERS	Bias stability of < 130 micro g or Scale factor stability of < 130 ppm or Specified to function at linear acceleration levels > 100 g on any platform See Figure 7.2-3	None identified	Specially designed test, calibration, or alignment equipment Accelerometer axis align stations Programmable dividing head CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
MULTI-FUNCTION INERTIAL COMPONENTS	Combination of gyro and accelerometer parameters with limiting tolerance parameter being a drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or specified to function at linear acceleration levels > 100 g on any platform	None identified	Specially designed test, calibration, or alignment equipment Accelerometer axis align stations	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
AZIMUTH DETERMINATION SYSTEM	< 3 arc minutes Refer to parameters for gyroscopes	None identified	Components require specially designed test, calibration, or alignment equipment	Algorithms and verified data needed for compensation	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
FLOATED GYROSCOPES	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Gyro dynamic balance station Gyro run-in motor test station Gyro evacuation and fill stations Centrifuge fixtures for gyro bearings	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
DYNAMICALLY TUNED GYROSCOPES (DTG)	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Gyro tuning test station Gyro dynamic balance station Gyro run-in motor test station Gyro evacuation and fill stations Centrifuge fixtures for gyro bearings	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
RING LASER GYROSCOPES (RLG)	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Scatterometers-accuracy < 10 ppm to characterize mirrors Profilometers-accuracy < 5 angstrom to characterize mirrors Gyro evacuation and fill stations Ion beam coating facilities Electron beam evaporation machines CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E

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Table 7.2-1. Inertial Navigation Systems and Related Components Militarily Critical Technology Parameters (Cont'd)

TECHNOLOGY	MILITARILY CRITICAL PARAMETERS MINIMUM LEVEL TO ASSURE US SUPERIORITY	CRITICAL MATERIALS	UNIQUE TEST, PRODUCTION, AND INSPECTION EQUIPMENT	UNIQUE SOFTWARE AND PARAMETERS	EXPORT CONTROL REFERENCE
ELECTROSTATICALLY SUPPORTED GYROSCOPES (ESG)	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Gyro evacuation and fill stations CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
FIBER OPTIC GYROSCOPES (FOG)	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Fiber winding machines CAD development tools for linking various design parameters	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
HEMISPHERICAL RESONATOR GYROSCOPES (HRG)	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Gyro dynamic balance station Gyro evacuation and fill stations Surface etching techniques	Algorithms and verified data needed to exceed militarily critical parameters. Unique compensation techniques	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
MICRO ELECTRO-MECHANICAL (SILICON) GYROS	Drift rate stability of < 0.01 deg/hr for < 10 g or Drift rate stability of < 0.5 deg/hr for 10 to 100 g or Specified to function at acceleration levels > 100 g on any platform	None identified	Specially designed test, calibration, or alignment equipment Accelerometer axis align stations Ion milling Plazma Arc Electronic Sputtering	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E
MICRO ELECTRO-MECHANICAL (SILICON) ACCELEROMETERS	Bias stability of < 130 micro g or Scale factor stability of < 130 ppm or Specified to function at acceleration levels > 100 g on any platform	None identified	Specially designed test, calibration, or alignment equipment Accelerometer axis align stations Ion milling Plazma Arc Electronic Sputtering	Algorithms and verified data needed to exceed militarily critical parameters. Error compensation for environmental effects and technology characteristics	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 9 USML VIII, 121.16 CCL Cat 7A, B, D, E

SECTION 7.3 RADIO AND DATA-BASED REFERENCED NAVIGATION SYSTEMS

Overview (See Figure 7.3-1) This subsection covers a limited category of technology and equipment having a wide range of dual-use applications. GNSS receivers with certain characteristics have proliferation concerns, especially when used in the differential and hybrid modes using compensating systems for improving accuracy and redundancy. Accurate time and frequency form the baseline for telecommunications and navigation. DBRN provides highly accurate position, velocity, and track under dynamic and **covert** conditions. DBRN systems use **prestored** ground and undersea terrain contour, acoustic, electromagnetic spectrum, magnetic, gravity, and stellar sensor data. Radio navigation equipment using low probability of intercept techniques also provides covert capability.

Rationale (See Table 7.3-1) Accurate positioning, control, and redundancy for platforms are essential for effective coordination of military activities. Individual system accuracies depend on mission requirements. Encrypted signals of the GPS deny nonauthorized users the full capability of the systems. Null-steerable antenna are a military response to jamming. Hybrid and DBRN systems combine the best features of different navigation systems to provide autonomous, covert, unjammable information. All radio navigation and DBRN systems rely on precise time and frequency. DBRN technology is partially derived from sensor and Geographic Information Systems (GIS) technology. DBRN technology, leveraged by computer speed and memory, resolves data ambiguities and optimizes navigational sensor and stored data. The use of power management and phase shift key modulation reduces the emitted signal resulting in a decreased detectability and covert (stealth) operation.

Foreign Technology Assessment (See Figure 7.0-2) The US and Russia have independently developed and deployed GPS and GLONASS, respectively. The US leads the world in radio navigation and DBRN technology and is progressively improving in the areas of accuracy, size, weight, reliability, cost, and integration with digital processing technology. The gap, however, is closing quickly as the newer technologies require, in some cases, less capital investment in the technology. Increased computational effectiveness for a given equipment volume and weight could provide an adversary with distinct navigation payoffs: (1) enhancing navigation capabilities and (2) improving reliability and resistance to hostile actions. Signal detection and processing technology is used to acquire, synchronize, and track desired signals for measurement of navigation parameters. The substantial margin of capability added by this technology is vital to continued US superiority in precision navigation and the multitude of missions dependent thereupon. Highly interference-resistant receivers for satellite navigation systems are also vital.

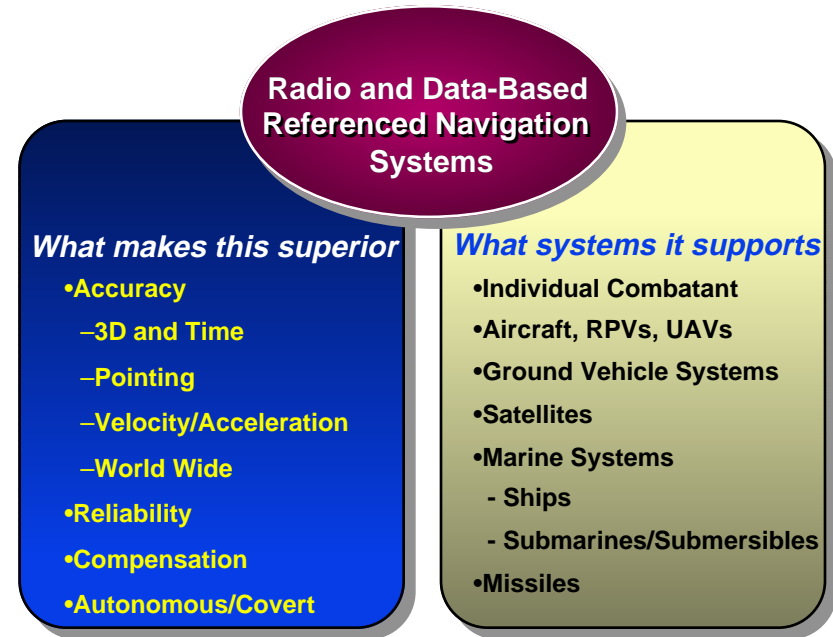


Figure 7.3-1. Radio and Data-Based Referenced Navigation Systems Overview

Militarily critical signal conversion technologies contribute directly to mission effectiveness by improved anti-jamming performance, increased reliability, higher precision navigation, real-time adaptive response to hostile environments, and decreased system size, weight, and cost. The know-how to achieve improvements most beneficial to military applications depends upon integrated circuit technology and the software to support it. In this area, Russia lags the US by 3 to 5 years. France, the UK, Germany, Israel, and Japan are the leading nations that have developed end-use products that use signals from both GPS and GLONASS and DBRN for military applications. The acquisition of dual-use end-products could allow the transfer of the necessary know-how for military applications. Russia has developed the use of magnetic arrays to improve compensation for DBRN systems.

Table 7.3-1. Radio and Data-Based Referenced Navigation Systems Militarily Critical Technology Parameters

TECHNOLOGY	MILITARILY CRITICAL PARAMETERS MINIMUM LEVEL TO ASSURE US SUPERIORITY	CRITICAL MATERIALS	UNIQUE TEST, PRODUCTION, AND INSPECTION EQUIPMENT	UNIQUE SOFTWARE AND PARAMETERS	EXPORT CONTROL REFERENCE
GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)	Signal decryption (anti spoof) and/or null-steerable antenna, jamming protection Accuracy of < 20 meter 50% SEP in position and < 200 nanosecond in time and < 0.1 m/s velocity for > 60,000 ft and > 1,000 kts	None identified	Selective Availability, Anti-Spoofing (SA/A-S) Signal Simulators with SA/A-S < 200 nanosecond measurement capability ECCM or Interference Resistance Receivers	Algorithms including classified, encrypted algorithms and verified data. Vehicle attitude determination	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 11 USML XII, 121.16 CCL Cat 7A, B, D, E
DIFFERENTIAL GNSS	Signal decryption (anti spoof) and/or null-steerable antenna, jamming protection Accuracy of < 1 meter 50% SEP in position and < 200 nanosecond in time and < 0.1 m/s velocity for > 60,000 ft and > 1,000 kts	None identified	Selective Availability, Anti-Spoofing (SA/A-S) Signal Simulators with SA/A-S < 200 nanosecond measurement capability	Algorithms including classified, encrypted algorithms and verified data. Differential techniques that provide accuracy of < 1 meter. Vehicle attitude determination	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 11 USML XII, 121.16 CCL Cat 7A, B, D, E
HYBRID NAVIGATION SYSTEMS	Accuracy of < 20 meter 50% SEP in position. Jamming protection to maintain PPS or < 0.1 m/s velocity for > 60,000 ft and > 1,000 kts For spacecraft - Pointing accuracy of < 50 arc sec	None identified	Components require specially designed test, calibration, or alignment equipment. GNSS receivers require special simulator testing systems. Specially designed test, calibration, or alignment equipment	Algorithms and verified data needed to exceed militarily critical parameters. Source code for combining INS with Doppler, GNSS or DBRN. INS initial align time code for moving platform, transfer align techniques and reference to geoid	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 11 USML XII, 121.16 CCL Cat 7A, B, D, E
PRECISION TIME AND FREQUENCY SUBSYSTEMS	Signal phase (time) communication synchronization < 100 microseconds, UTC (USNO). Intersystem synchronization < 100 nanoseconds relative to other system nodes. Navigation systems < 200 nanoseconds, UTC (USNO). Frequency for reference and calibration, $\Delta f / f < 1 \times 10^{-10}$.	Synthetic quartz Magnetic shielding materials, see Materials	Frequency for reference and calibration, $\Delta f / f < 1 \times 10^{-10}$	Algorithms and verified data needed to combine clock outputs to improve stability/accuracy performance (i.e., "Ensembling") Automatically detect phase jumps or frequency perturbations and/or improve reliability from redundancy. Self monitoring.	WA Cat 3A, B, D, E MTCR 12 USML XII, 121.16 CCL Cat 3A, B, D, E
RADAR ALTIMETERS AND DOPPLER NAVIGATION SYSTEMS HAVING POWER MANAGEMENT OR PHASE SHIFT KEY MODULATION	Non detectable – in radar frequency range	None identified	None identified	Cross correlation algorithms and verified data.	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 11 USML XII, 121.16 CCL Cat 7A, B, D, E
DATA BASED (FOR EXAMPLE TERRAIN, ACOUSTIC, ELECTROMAGNETIC SPECTRUM, MAGNETIC, GRAVITY, GRAVITY GRADIENT, BATHYMETRIC, STELLAR) REFERENCED NAVIGATION	Accuracy < 100 meters CEP	None identified	Unique computer test models for optimization of data base manipulation and extraction	Algorithms for image correlation and pattern recognition. Integration and data analysis algorithms and verified data	WA ML 9, 11, 21, 22 WA Cat 7A, B, D, E MTCR 11 USML XII, 121.16 CCL Cat 7A, B, D, E