1. General Technical Specifications

The baseline design has been derived from the experiences with similar systems and especially with the BIRD sat test bed. Various modifications and enhancements result in the sophisticated state-of-the-art ACS test bed. It allows for verification of any small satellite, as long as sensors and actuators are applied according to the technical description given within the proposal.
The ACS test bed consists of the following subsystems:

- Air-bearing table including safety mechanism
- Air compressor with air treatment unit
- Platform with electronic centre of gravity (CoG) calibration
- Earth-magnetic-field simulation by Helmholtz-coil system
- Sun simulation
- Power supply
- Special equipment and WLAN for CoG calibration.

Figure 1: ACS Test Bed, with Sun and Magnetic-Field Simulation

Table 1: Parameters of the ACS Test Bed

Parameter	Description
Dimension	approximately Ø3800 x 3110 mm, incl. sun simulation
Total mass	approximately 350 kg on 4 m² (square meters)
Max. performance time at average power load	depending on electrical load of the test object (useable battery capacity > 400Wh) max. performance time of the test facility >24h
Power supply	230 V, 50Hz, < 4,6 kW (sun simulation max. 2 kW, compressor approx. 1,6 kW)
Compressed Air Supply	own compressed air production (compressor) pressure hose length approximately 8 meters
Clearance for Delivery	tbd
Requirements on Installation Location	tbd

The subsystems of the ACS test bed are defined in the following paragraphs.

1.1 Air-Bearing Table with Safety System and CoG Calibration

The air-bearing table is the vital component of the ACS test bed, providing extended degrees of freedom (360° vertical axis and ±15° horizontal axes) almost without any moment disturbance.

The air-bearing table consists of a stand, a calotte and a hemisphere. The mechanical interface (adapter plate) to the platform is on the flat side of the air-bearing hemisphere. Special nozzles inject an air cushion between calotte and hemisphere that will be adjusted to the applied load. Hence, the nearly frictionless bearing benefits the platform and the test setup. The air bearing is placed on a stand allowing for height adjustment, thus, test setup can be placed in the center of the magnetic field simulation.

The safety mechanism prevents crashes of sphere and calotte in case of accidental pressure or power loss, thus the whole setup is protected against damage by accidental shocks. The safety mechanism also fixes the parking position (for non-operating mode and for alterations of test setup on the platform). The sphere will be lifted up above the calotte by the mechanism mounted to the platform. There is a display to show the height above the calotte.

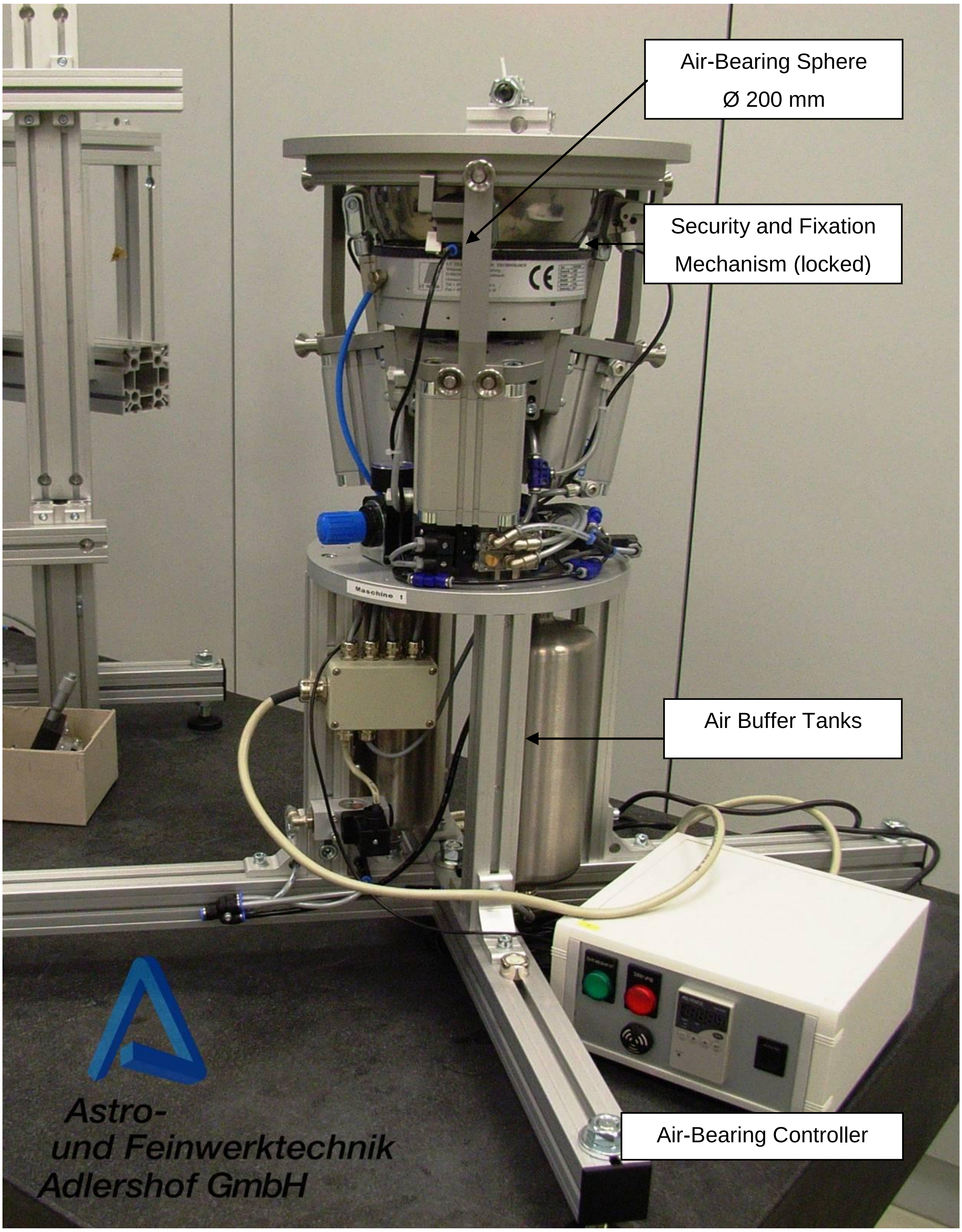

Figure 2: Air-Bearing Table without Platform

Non-magnetic materials will be utilized to avoid interference with the simulated magnetic field.

Table 2: Parameters of Air-Bearing Table

Parameter	Description
Disturbance Moment	$<10^{-5}$ Nm
Effective Degrees of Freedom	rotation z-axis 360° (free) rotation x- and y axes +/- 15°
Maximum Load / Maximum Mass on Table (mass of test object):	50 kg to 120 kg
Moments of Inertia	2 to 7 or 15 to 30 kgm^2 for micro and mini satellites (see Figure 4)*
Table Height	800 mm to 1000 mm
Adjustment of Test Setup CoG to Sphere Center	see 1.2
Air Injection	centrally, at the bottom
Air Gap	8 µm to 20 µm
Miscellaneous	adjustable feeds

*Smaller platform can be designed, but in that case without DC/DC support for test object

1.2 Platform and CoG Calibration

The platform comprises a mounting plate with mechanical interface to the air-bearing hemisphere, four beams on the bottom and three trimmer beams. The four beams and weights are applied for manual rough adjustment of CoG. Three beams with three identical trimmer weights driven by step motors are used for trimming, they are at opposite sides of the platform.

The laser pointer, the motor controller, the radio link, and the power module (batteries, dc/dc converter) are mounted on the bottom of the platform. The whole mounting plate is available for test setup. It is equipped with a universal matrix of holes to mount ACS components.

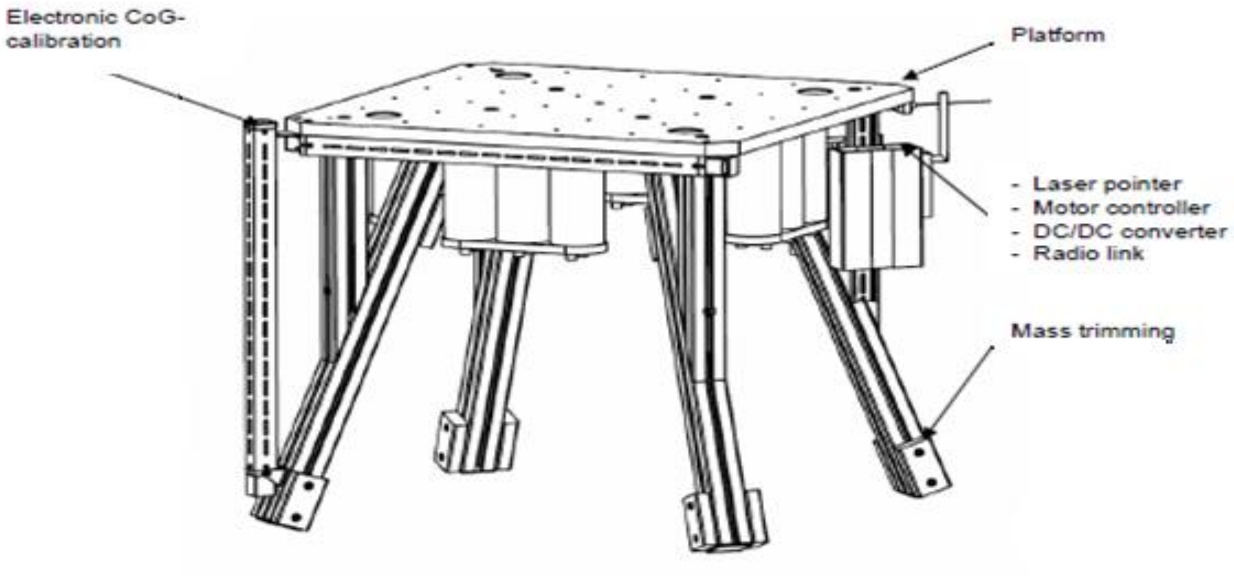

Figure 3: Platform for Moments of Inertia between 2 and 7 kgm²

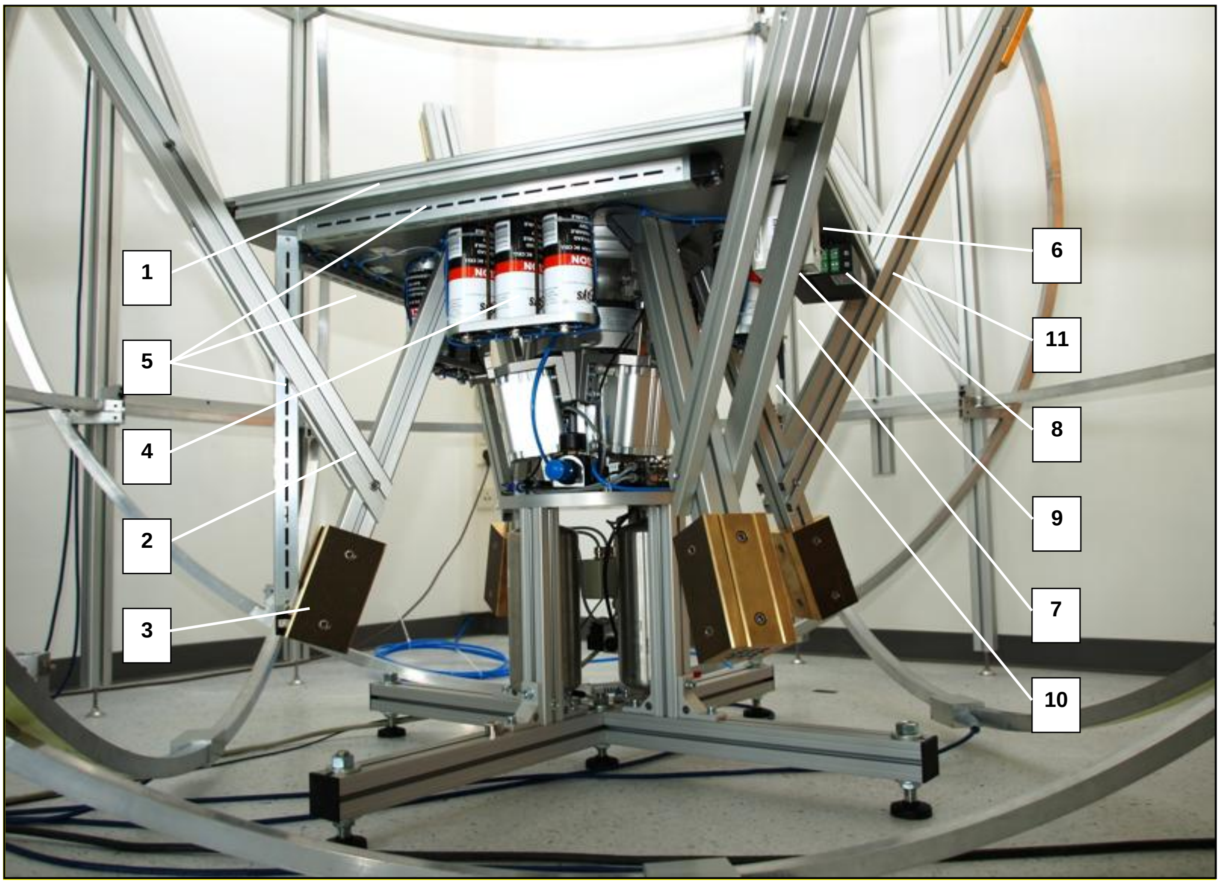

Figure 4: Platform for Moments of Inertia between 15 and 30 kgm²

List of components shown in figure above:

1. Platform for ADCS components
2. Structure for high moment of inertia
3. Trimming mass
4. Batteries
5. Fine trimming mechanism (via WLAN)
6. Mounting area for controller
7. Controller for fine trimming mechanism
8. DC/DC converter for ADCS components
9. WLAN interface
10. Wireless switch
11. Laser pointer

Table 3: Parameters of Platform and CoG Calibration

Parameter	Description
Dimensions	600 mm x 600 mm
Mass of Platform (incl. batteries, radio link, power module, interface to hemisphere)	≈ 50 kg
Mechanical Interface on Platform	36 x M4 - grid 100 mm x 100 mm
Torque of Inertia [kgm²]*	2 to 7 or 15 to 30 in all axes ± 10 %
Range for Rough Adjustment	10 kg @ 150 mm in x/y 20 kg @ 400 mm in z
Range for Trimming	10 g @ ± 250 mm (correspond to ± 0,025 Nm in horizontal plane)
Accuracy of Trimming	10 g @ ± 0,1 mm (correspond to ± 0,00001 Nm in horizontal plane)
Display for Rough Adjustment	1-mm steps
Display for Trimming	0.1-mm steps

*Smaller platform can be designed, but in that case without DC/DC support for test object

1.3 Air Compressor and Air Treatment

The compressed air supply is adequately dimensioned to ensure the performance of the air-bearing table at any allowable load with respect to tolerances of air gap and supply to safety mechanism. Air vessels stabilize the compression ratio. Additionally, the buffer tanks of the air bearing support the safety mechanism in case of compressor failure or leakage in the tube.
The air will be filtered and dehydrated.

Table 4: Parameters of Air Compressor

Parameter	Description
Permanent Performance	24h
Compressor	max. 8 bar
Air Buffer Tanks / Vessel	20 liter (all together)
Air Dryer	yes
Pre- and Fine / Final Air Filter	yes

1.4 Earth-Magnetic-Field Simulation by Helmholtz-Coil System

With respect to the challenging performance parameters for the magnetic-field simulation, a Helmholtz-coil system has been developed. The outer HH coil system comprises 3 x 2 air-core coils. Hence, the magnetic-field vector can be oriented in each direction. The system also enables a homogeneous magnetic field in respect to a defined volume.
The strength of the magnetic field is determined by the current flow in the coil pairs. Each coil pair has its own power supply and regulator. Inputs for magnitude and orientation of the magnetic field can be placed manually or fully automatically (computer aided calculation of simulated orbit parameters).

Table 5: Parameters of Magnetic Field Simulation

Parameter	Description
Magnetic Field Power	≈ 200,000 nT
Angular Accuracy	<1% (in centre)
Degrees of Freedom	full 360° in all axes
Power Supply	incl. 3 bipolar power supply units, controllable by computer
Time Stability	minimum 8h without heating of the coils above 30 °C at room temperature (21 °C)

Table 6: Parameters of Helmholtz Coils

Parameter			Description of HH-Coil
Dimensions of the System [m]			2,40 x 2,40 x 2,30 (L x B x H)
Dimension [m] of the Biggest Part (to prepare for transport)			2,40 x 2,40 x 0,03 (L x B x H)
Mass [kg]			ca. 110
Mass [kg] incl. Container			ca. 200
Coil Diameter [m]			2,40 / 2,30 / 2,20
Homogeneity for 90 cm Cube (ca.)			
	x / y – direction	[100]	1,5 %
	xy – diagonal	[110]	6,5 %
	z – direction	[001]	3 %
	xz / yz – diagonal	[101]	5,5 %
	xyz – diagonal	[111]	15 %
Field Factor [µT/A]			≈ 70 - 80

1.5 Sun Simulation

The sun simulation consists of a 575 W metal halide (HMI) lamp and a reflector on a stabile, movable assembly (see Figure 1). The setup provides high intensity and homogeneity of illumination as well as low thermal stress on test setup.

Table 7: Parameters of Sun Simulation

Parameter	Description
Sun Simulation	∅ ≈ 500 mm with ~ 50.000 lx
Thermal Radiation	low by use of metal halide lamp and colt light mirror
Termal Dissipation loss	low
Average life of the 575 W Metal Halide (HMI) Lamp	approx. 1000 h
Rotational Freedom	around z-axis ± 180°, around x,y-axis ≈110°
Luminous Flux Adjustment	from 40% to 100%

Note to protection:

The distance between the metal halide lamp and the wall or ceiling must meet the appropriate national building regulations (radiated head). The distance from the metal halide lamp to any illuminated object must be at least 0.7 meters.

Please instruct personnel to avoid standing directly in the light beam.

1.6 Power Provision

The power supply covers the power demands of test bed components, motor controller for CoG calibration and WLAN radio link, as well as providing for the ACS components, the TM/TC line and the board computer.
The voltage of 24V for operation of test bed hardware and ACS components can be tailored for special ACS components via DC/DC converter modules providing the rated power at the voltages needed. The supply for test bed hardware and ACS components is separate. Hence modifications to meet the supply demands for new ACS components can be implemented more easily.

Table 8: Power Supply Parameters

Parameter	**Description**
Power Requirement of all Necessary Components on the Platform incl. ACS – Components	max. 83 W peak max. 30 W nominal
Maximum Operating Time at Average Electrical Demand	depending on electrical load of the test object (useable battery capacity > 400Wh) max. performance time of the test facility > 24h
Constructional Arrangement	below the platform
Batteries	12 pieces Cyclone-BC-Cells each 2 V, 25 Ah; total mass $\approx$ 26 kg
Charger	a charger for the Cyclone BC-Cells is included to scope of delivery

For the test facility components (motor controller, WLAN module) and ACS test facility components will be realized as a split power supply. The power supply for the motor controller/motor for CoG calibration and for the WLAN module can be switched off and on by radio control.

The power requirements for the ACS components will be supported by a six-way DC/DC module.

1.7 Special Equipment and Wireless CoG Calibration

The control processor (standard PC e.g. IBM Think Centre with network interface) sends the necessary input commands for CoG rough adjustment and trimming via WLAN to the actuators onboard the platform. A virtual COM-Port-driver connects to the RS232-WLAN-module via TCP and will be used as a normal COM-Port. The RS232 WLAN module converts TCP and RS232 protocols according to IEEE 802.11.

The software used to adjust the parameters of the 3 motors on the ACS test bed, shows current motor status and defines the target state of the motor.

C/C++ or LabVIEW® will be used to program the software.

The PC can also be used to control the power supply to the magnetic coil system used for the simulation of the earth’s magnetic field.

1.8 GPS Simulation

1.8.1 Hardware GPS

The signal generator uses direct digital waveform synthesis resulting in an accurate, stable generator capable of high fidelity and resolution. Communication between the signal generator and the simulation software PC is by USB. Data transmission is synchronized by an embedded 1PPS 'tick'.
The Multi-GNSS Simulator signal generator chassis is housed in a 2U, full width rackmountable2 case and is powered via the ac mains connector. The rear panel mounted fan provides forced-air cooling. The primary RF output is fitted on the front of the unit. All other connections are accessed via the rear panel. Calibration adjustments may also be made via the rear panel.
The Multi-GNSS Simulator will be delivered as GPS L1 simulator for to 12 channels. Note that constellations not specified at initial purchase may be enabled subsequently by a straightforward field upgrade process. This process does not require the unit to be returned to the factory and can be performed by the user.
The unit includes a temperature controlled crystal oscillator and its signal is made available for external use. Alternatively, the generator may be locked to an external frequency reference signal. A selection of external reference frequencies is supported. The simulator can be synchronized with other test equipment using its 1PPS input and output signals. Correct operation of the unit can be confirmed from the front panel indicators or remotely using BITE (Built in Test Equipment) interrogated over one of the digital interfaces.

1.8.2 Software of GPS Simulator (GSS)

The Multi-GNSS Simulator (GSS) provides a coherent simulated signal from GPS satellites at the L1 frequency. Generation of signals from the various constellations is enabled by license key. If all license keys are present, the Multi-GNSS Simulator can generate 12 channels of GPS concurrently.

When operated with Software for Windows software the GSS generates similar RF signals to those that would be seen by a GNSS receiver when installed on a vehicle with time, place and motion defined by the user in a test "scenario". This enables the performance of the receiver to be assessed in the laboratory as if it were receiving RF signals from real satellites whilst stationary or performing complex user defined maneuvers. Standard features enabled by simulation software include simulation of multipath reflections, terrain obscuration, antenna reception gain patterns, differential corrections (currently only specified for GPS), trajectory generators for a range of vehicles and comprehensive error generation and system modelling. The GSS can be used on its own or integrated with other equipment using a comprehensive remote control command set. System extensions available from Spirent include interference and noise generation, automotive sensors and local area augmentation (LAAS) VHF data broadcast (VDB) simulators. “Truth” data from the simulation is available to facilitate results analysis or integrate with other systems for hardware in the loop applications.

Models

Simulation software contains a collection of mathematical models it uses to control the generation of the RF signals. The coefficients for these models are stored in the scenario data files generated by the editors.

Each model has a default case to facilitate rapid scenario generation whatever the GNSS experience of the user.

Satellite modeling

The Simulation software is able to calculate position, velocity, orbital trajectory plus almanac and ephemeris data of up to 12 navigation satellites in user-defined constellations. Definition of the constellations is via file editors that independently describe the orbits of the satellites in the terminology of the relevant ICDs.

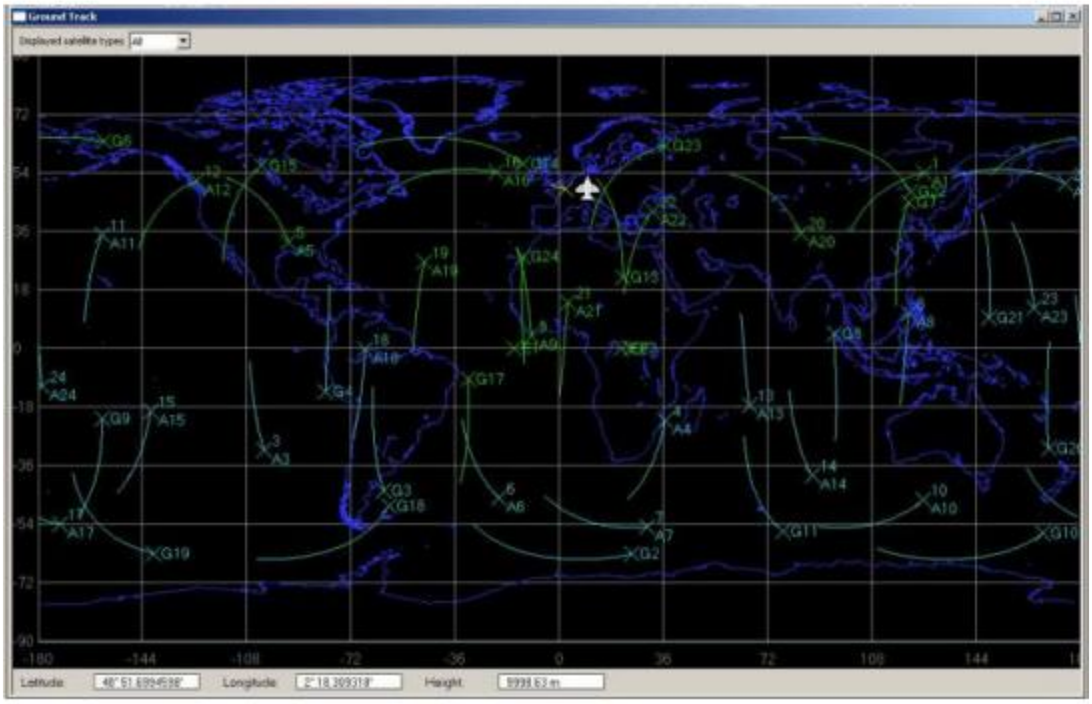

Figure 5: Satellite ground tracks

A wide range of user controls and error functions are also supported including the ability to enable or suppress elements of the transmitted signals on a per-satellite basis.

<u>Ground-segment modeling</u>

The simulation software allows the user to command a variety of Ground Segment activities. A facility is provided to periodically remove any satellite from the simulated constellation and for this to be reflected in the transmitted Navigation Data message where appropriate.

Any Ephemeris or Almanac is derived directly from the orbital definition specified by the user. The data is extrapolated from the time-of-validity in the source file to the value that would be valid at the simulated time, including divergence after upload. This relieves the user of the need to relate constellation file data to simulation date and time. Data uploads and Ephemeris cutovers are fully supported where appropriate.

Facilities are provided to specify the satellite health data fields and to manipulate various specific data fields and flags in the data messages. In addition, bit-wise message editors are included that allows manipulation of any field though bit forcing, clearing and inversion, whilst maintaining valid parity.

1.8.3 Deliverables of GPS Simulator (GSS)

Additional to the system described above, there will be a re-radiation kit, that allows the submitting of the GPS system without cable over a typical distance of 15 cm.

Table 9: Deliverable Items of GPS simulation system

Item	**Quantity**	**Description**	**Comment**
1	1	Multi-GNSS Signal Generator	For 12 channels GPS-L1
2	1	Vertical mount foot	
3	1	PC	
4	1	Data CD	Contains Simulation software and manuals
5	1	USB cable	
6	1 set	Power cords	
7	1	License Key	
8	1	Reradiation kit	

2. Tailoring the ACS Test Bed Baseline Design

The design will be tailored to customer’s need, if requested, within the parameters specified.
The platform load and moment of inertia can be redesigned in accordance to the customer requirements. Hence, we assume minor re-design of the air bearing (e.g. nozzle geometry) with respect to optimized performance. The power supply with respect to the DC/DC converters will be redesigned with regard to the customer’s needs.

3. List Price

3.1 Cost Price Data

The costs arise in the following areas in accordance with the scope of performance:

- management tasks
- procurement and manufacturing
- Integration at customers facility
- AIV
- Tests
- training
- technical documentation
- commercial documents: certificate of origin (3), commercial invoice (3), packing list (2), specification, movement certificate, document for export

Type of price: List Price
Currency: Euro

3.2 Cost Breakdown

Item	List Price in EURO
ACS Testbed	300.000,00
Magnetic Field Simulation	100.000,00
Sun Simulation	75.000,00
GPS Simulation System	100.000,00
Training	40.000,00
Packet Price	**600.000,00**

4. Abbreviations

ACS	Attitude Control System
AFW	Astro-und Feinwerktechnik Adlershof GmbH
AIV	Assembling Integration Verification
BAFA	Federal Office of Economics and Export Control
CAD	Computer Aided Design
CoG	Centre of Gravity
DC	Direct Current
DGQ	German Foundation of Quality
DIN	German Industry Standard
DLR	German Aerospace Centre
EN	European Standard
ERP	Enterprise Resource Planning
ESA	European Space Agency
FMEA	Failure Mode Effects and Analysis
FMECA	Failure Mode and Effects and Criticality Analysis
GSS	Multi-GNSS Signal Generator
HILS	Hardware-In-the-Loop Simulations
HH	Helmholtz
H/W	Hardware
ILS	Integrated Logistics Support
ISO	International Organization for Standardization
MGSE	Mechanical Ground Support Equipment
OGSE	Optical Ground Support Equipment
PCU	Packet Control Unit
PDU	Protocol Data Unit
QA	Quality Assurance
RFI	Request for Information
RFQ	Request for Quotation
SILS	Software-In-the-Loop Simulations
STI	Space Technology Institute
S/W	Software
TC	Tele Command
TCP	Transmission Control Protocol
TM	Telemetry
VAT	Value Added Tax

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