Forsvarets forskningsinstitutt

Technical Requirements 45/2010

Stabilised platform for multisensor turret/pod

Description of technical requirements for stabilised platform for multisensor turret/pod, tendering document 45/2010.

Forsvarets forskningsinstitutt (FFI)
Norwegian Defence Research Establishment

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Contents

1. Requirements prerequisites

The technical requirements listed in this document are a result of the intended use of the research pod accommodating the stabilised platform of this procurement. To give the tenderer a better understanding of the motive and intention of the requirements, and to make the tenderer able to tailor his stabilised platform systems to better fit our needs, a more detailed description of the intended use of the NG-NFU research pod is included below.

1.1. Captive carry research pod

The research pod will be embedded in the modified airframe of a MXU-648 cargo pod manufactured by Sargent Fletcher, as shown in Figure 1.1**Feil! Fant ikke referansekilden.**. The modified pod consists of a conical aft section and a cylindrical centre section. The nose section of Figure 1.1 will be replaced by a custom nose section constructed by FFI, shown in Figure 1.3. There are two service latches in the centre section, and provisions (removable covers) for antennas in aft and fwd conical sections.

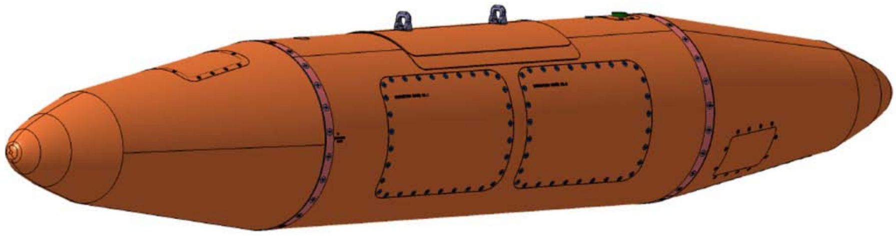

Figure 1.1 Modified MXU-648 Cargo/Travel pod for Norwegian Captive Carry program. Nose section to the left will be replaced with custom nose section constructed by FFI

The custom nose section will accommodate the stabilised platform with the payload consisting of forward-looking electrooptical (EO) sensors. The platform shall in-flight enable stabilisation of the sensor field of views (FOVs) and manage to slew the FOVs over the field of regard (FOR). The LOS is defined as the centre of FOV.

Figure 1.2 shows an illustration visualizing the FOV/FOR/LOS-terms used. The yellow solid square indicates sensor field of view (FOV). The centre of the FOV is marked with a red '+' and is denoted as line of sight (LOS). (In this example the LOS is currently straight and level at (0°, 0°).) The outer red rectangle shows the LOS movement physical limit envelope of the stabilised platform. The dotted black rectangle inside the red illustrates a defined LOS limit envelope which is determined by the lesser of the physical limit of movement envelope and mechanical restrictions due to surrounding structure (e.g. pod nose cone) - minus a buffer required for angular vibration noise stabilisation.

The LOS limit envelope defines the area over which the platform is free to slew the LOS.

The yellow rectangle outside the red rectangle shows the total field of regard (FOR) when slewing the FOV within the defined limit of LOS envelope.

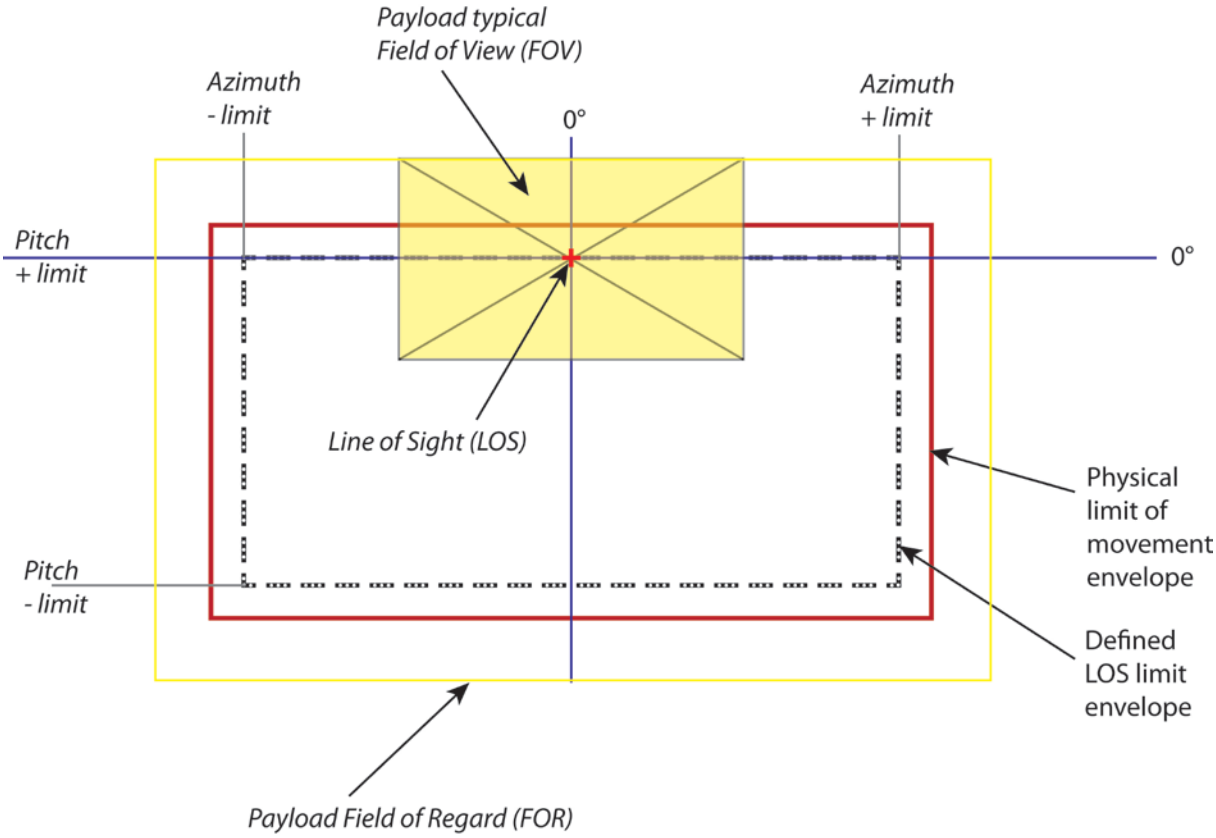

Figure 1.2 Description of terminology.

When discussing pitch and azimuth slew angle limits in this document we refer to the defined limit of LOS envelope, not the physical limit of LOS movement envelope.

During the service life of the research pod the payload will be changed several times, requiring a high level of platform flexibility.

Figure 1.4 shows a forward view of the custom pod nose section with windows transparent to the payload. Figure 1.5 shows a visual transparent nose cone section, revealing the internal payload components. The stabilised platform in this picture is for illustration purposes only and should not be used as guidance for design.

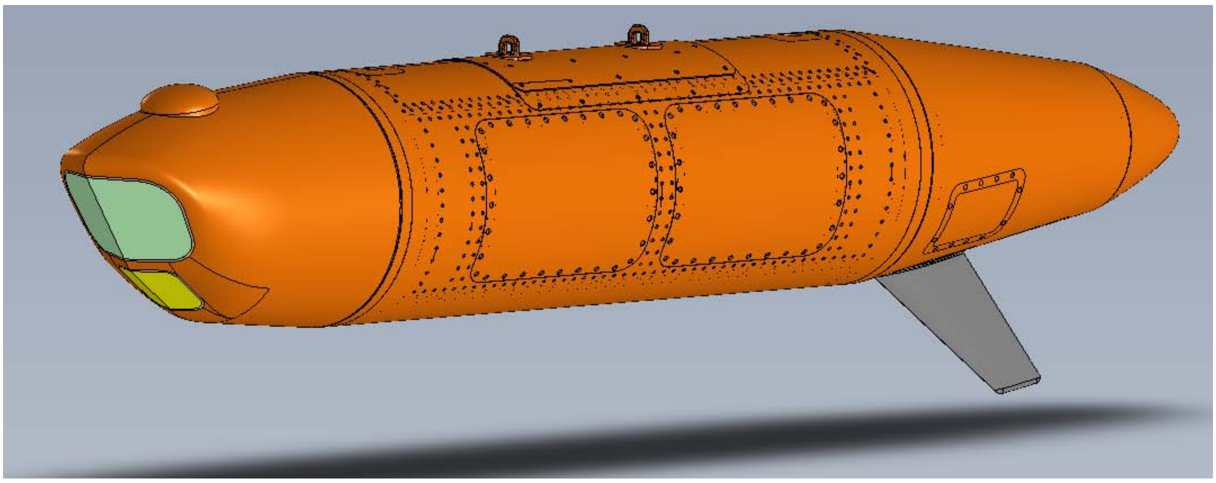

Figure 1.3 Modified MXU-648 (NG-NFU) pod with custom nose section and tail cone antenna.

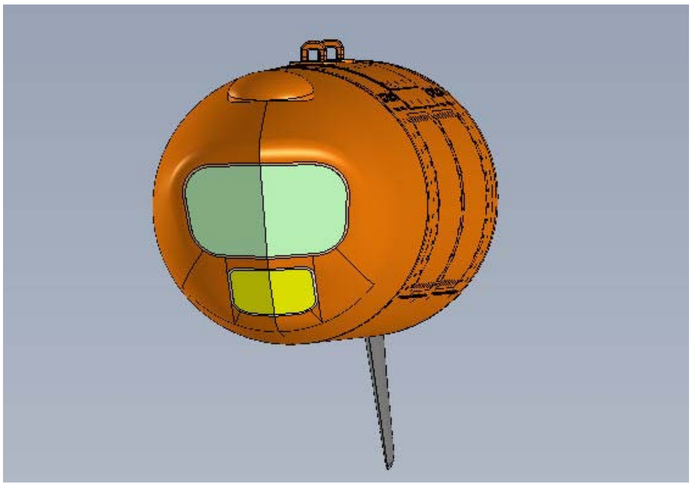

Figure 1.4 Pod forward view showing custom nose section with window arrangement

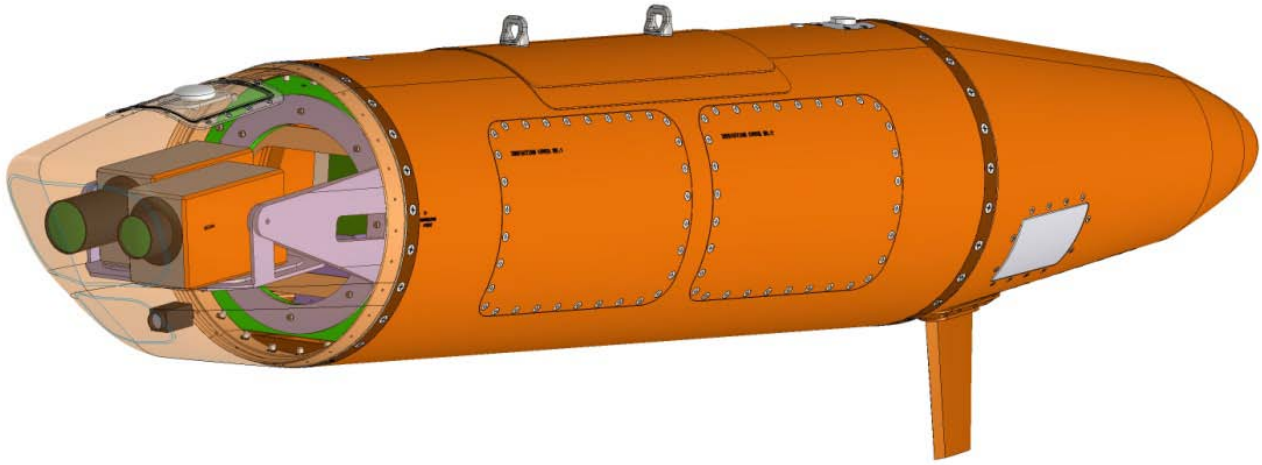

Figure 1.5 NG-NFU with transparent nose section revealing payload arrangement and a stabilised platform for illustrative purposes

1.2. Operational environment

The missions of the research pod will consist of in-flight recording and real-time processing of sensor data. A number of 15-40 missions will be flown every year for the next 20+ years.

The operational environment will often be near or at sea with high levels of humidity, salt and a wide range of operation temperatures from low transit temperatures at high altitudes to high temperatures at low altitudes in summer adding the heating effects due to aerodynamic friction.

Appendix A shows lateral and vertical vibration levels for a set of test points (F-16 manoeuvres) measured in the pod nose compartment. The platform shall be designed to operate in these conditions. Use the straight line of “MIL-STD-810F Jet Aircraft Store Buffet Response”, expand it to 2.5 kHz and use for design purposes. Given the length from nose to pod axis centre these vibration levels will impose an angular vibration noise of 0.44° (5 σ value) that the platform should be able to stabilise.

1.3. Connection to a guidance system

The platform will be an integrated part of a navigation system, connected through a guidance computer. There is a reference Inertial Measurement Unit (IMU) of the type Honeywell HG9900 mounted close to the stabilised platform. The mechanical connection between the IMU and the platform mounting base (strongring) can be considered to be stiff. Data from the IMU will be used to generate accurate navigation data that can be made available to the stabilised platform electronics if requested, reducing the need for separate platform motion sensors. The navigation data is available through a Ethernet TCP/IP client/server interface at a rate of 300Hz, with the listed navigation parameters:

- Latitude / longitude
- Height
- Roll / pitch / heading
- Velocity
- Acceleration

Figure 1.5 shows a schematic view of the navigation system including the platform with imaging sensors.

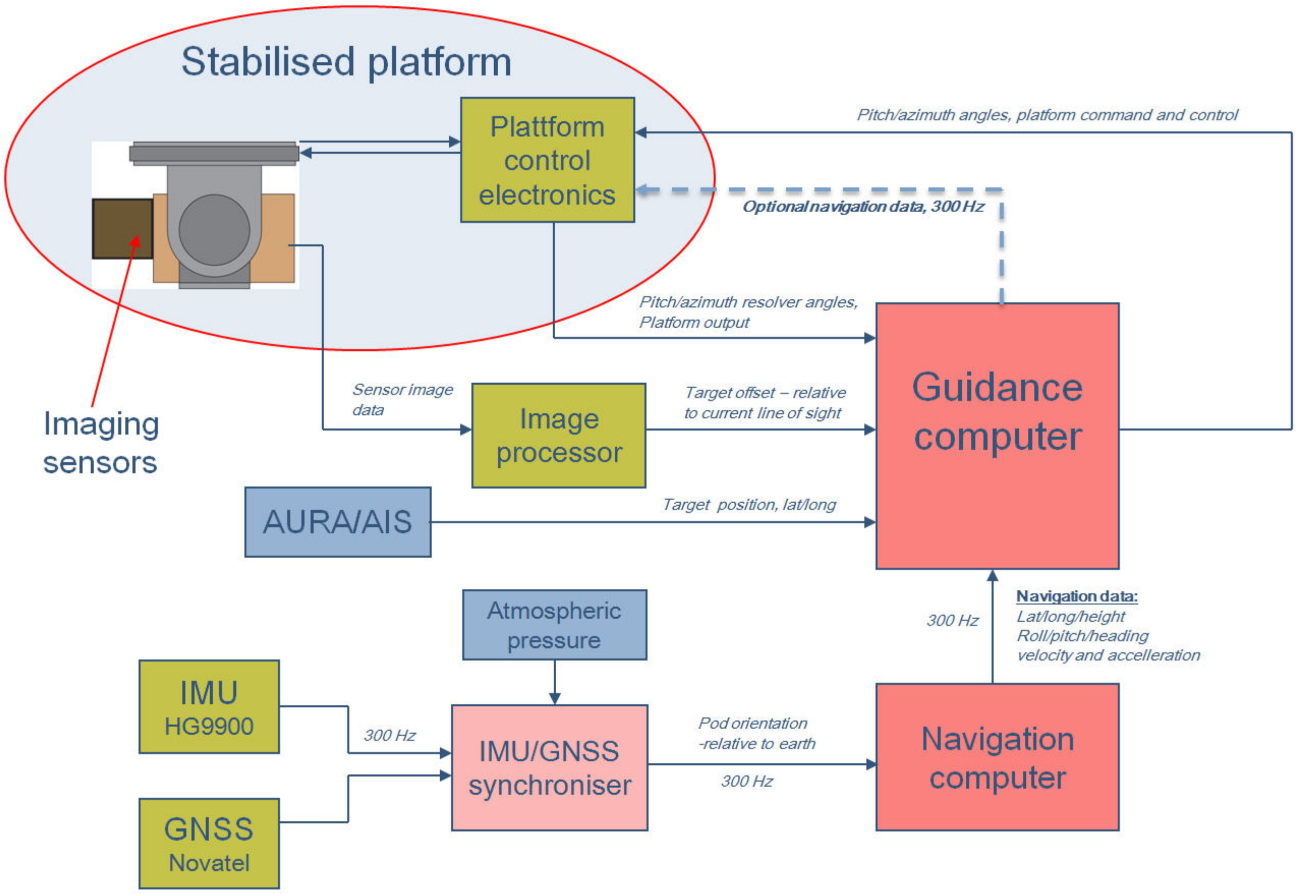

Figure 1.5 **Stabilised platform integration to pod navigation/guidance system. The stabilised platform of this procurement with payload is circled. All other components are NG-NFU pod internals.**

1.4. Platform modes of operation

The stabilised platform will have three main modes of operation, each of which are described below. These modes will be referred to in chapter 2 Technical requirements.

<u>MODE 1 – stabilise platform orientation referenced to pod centreline:</u>
In this mode the platform will receive a set of LOS pitch/azimuth angles from the guidance system and should slew the LOS to this orientation <u>relative to pod centreline</u> and stabilise angular vibration noise at these pitch/azimuth angles (until LOS pitch/azimuth angles are updated by guidance system).

> E.g. the jet aircraft is on a long inbound attack with no target location information. In this case we would like the platform to keep LOS at {pitch=0°, azimuth=0°} (straight ahead along pod centreline), no matter what manoeuvres the aircraft performs, and at the same time stabilise any angular vibration noise. The platform must separate angular noise from aircraft manoeuvres, and tuning of this will require flexibility in platform configuration.

<u>MODE 2 – stabilise platform orientation referenced to earth:</u>
In this mode the platform will receive a set of LOS pitch/azimuth angles from the guidance system and should slew the LOS to this orientation and stabilise the LOS to point at this direction <u>relative to earth</u> regardless of aircraft manoeuvres, while stabilising angular vibration noise. (Guidance system pitch/azimuth angles will be a set of angles relative to pod centreline.)

> E.g. the real-time processor of imaging sensor data is detecting a target 2° starboard and 1° down relative to the pod centreline. This information will be forwarded to the guidance system that will command the platform to slew the LOS to the target position. Angular vibration noise should be stabilised, and the platform should point the LOS at these angles (relative to earth) regardless of aircraft manoeuvres. As the aircraft to target distance changes the pitch/azimuth angles will be updated by the guidance system (based on e.g image data or target distance estimates) and forwarded to the platform electronics.

<u>MODE 3 – power off:</u>
At transport/transit flights, when being transported by land, or whenever pilot shuts off power to the pod station, the pod will be non-operating and have no electrical power. The stabilised platform must include mechanisms to prevent the payload or platform from being damaged by free-floating movement.

1.5. Requirement grading

Requirements formulated with "**shall**" must be fulfilled. In case one or more “**shall**” requirements disqualify all contractors, the requirements will be re-evaluated by FFI and in this case all tenderers will be informed.

Requirements formulated as "**should**" are graded in 3 levels:

should (1)	Requirements that are vital to achieve the goal of the purchase.
should (2)	Requirements that are important contributions to increase the capabilities of the research pod.
should (3)	Requirements that increase the usefulness or user friendliness of the research pod.

The words “shall” and “should” describe the requirement when they are in bold letters.
The word “platform” refers to the stabilised platform system.

2. Technical requirements

2.1. Technology

a) Platform **shall** include active angular stabilisation in azimuth (horizontal) and pitch (vertical) axis.

b) The platform **shall** include reference motion sensors where navigation data from the guidance system is insufficient or not used.

c) The platform **shall** include reference position sensors.

d) The platform **shall** include platform control electronics with software to communicate with the pod guidance computer.

2.2. Mechanical and environmental

a) Platform **shall** fit inside the volume described in Appendix B.

b) Platform pitch axis rotation centre **should (2)** be close to vertical position 20mm above pod centreline as shown in Figure B.2.

c) Platform azimuth axis rotation centre **should (1)** be at (lateral) position along the pod centreline.

d) Platform pitch and azimuth axis rotation centre **should (1)** be at (longitudal) position as far forward as possible. Figure B.2 suggests a longitudal position at 298 mm in front of forward strongring. Add necessary weights at platform nose to balance the payload due to this "offset" of longitudal pitch/azimuth axis centre relative to the payload centre of gravity (CG).

e) Platform **shall** have mounts for attaching cantilevered arms from strongring, functional description shown in Figure 2.1.

f) The platform **should (3)** include cantilevered arms with strongring interface ring attaching the platform mounts to the front flange of strongring, functional description shown in Figure 2.1.

g) Platform including payload **should (1)** be structurally checked for yield loads, with no permanent deformation allowed and no degrade/inhibit of mechanical operation or requirement for maintenance after release of loads. Yield loads are obtained by multiplying the limited load factors in Table C.1 by 1.15.

h) Platform including payload **should (1)** be structurally checked for ultimate loads, with no separation of platform or any of its parts from attachment and no material fractures occurring at ultimate or lower loads. Ultimate loads are obtained by multiplying the limited load factors in Table C.1 by 1.5.

i) Platform **shall** have necessary adaptations to pass cables between payload and off-platform equipment, without limiting performance.

j) Platform mechanical design **should (1)** include adoptions for preventing corrosion and reduced performance due to operation in a harsh environment as described in section 1.2.

k) Platform electronics design **should (1)** include adoptions to operate in the harsh environment as described in section 1.2. Such adoptions could include board coating, additional fastening of components, etc.

l) Platform **should (1)** be capable of handling a payload weight of 15 kg, not including brackets and fasteners.

m) Platform **should (2)** be capable of handling a payload weight of 20 kg, not including brackets and fasteners.

n) Platform **should (1)** have a volume for payload described as a front to back (longitudal) rectangular opening / through-hole of minimum 224mm (width) x 245mm (height) positioned with pod centreline at 76 mm below top of opening as shown in Appendix D Figure D.5.

o) Platform **should (2)** have a volume for payload described as a front to back (longitudal) rectangular opening / through-hole of minimum 250 mm (width) x 265 mm (height) positioned with pod centreline at 86 mm below top of opening.

p) Platform **should (2)** have mechanical flexibility to add and move brackets and fasteners for payload mounting within payload volume.

q) Platform **should (1)** operate with surrounding air temperature in the range of -10°C to 60°C without reduced performance.

r) Platform **should (2)** tolerate non-operating temperatures in the range of -20°C to 80°C

s) Components off-platform requiring forced cooling **should (3)** have adaptations for liquid cooling and not use fans. Facilities for liquid cooling are available in the pod.

t) Platform weight (excluding cantilever arms and payload) **should (1)** not exceed 10 kg.

u) Platform weight (excluding cantilever arms and payload) **should (2)** be as light as possible.

v) The Royal Norwegian Air Force (RNoAF) restricts the use of batteries on jet aircraft external stores. Any platform batteries **shall** be certified for use on jet aircraft external stores.

w) Electrical cables **should (1)** have insulation resistant to heat and not emit toxic gases in case of fire. Approved electrical cable insulation is e.g. Teflon.

2.3. Electrical and software

a) Platform **should (2)** operate on a DC supply voltage of 28V DC.

b) Platform **should (3)** operate on a DC supply voltage covering the range 20V-32V.

c) Platform connectors **should (3)** be compliant to the MIL-DTL-38999 standard.

d) The platform system **should (1)** have a platform control software interface enabling reading and writing all relevant platform settings and setup parameters.

e) The platform software interface **should (2)** be implemented using a TCP/IP client/server architecture.

f) The platform software interface **should (3)** be implemented using a common computing communications standard.

g) Resolver position sampling **should (2)** in real-time be signalled using a hardware output signal (TTL or similar). This signal will be used to apply an accurate timestamp to position data.

h) Resolver position data output from platform software **should (1)** be output at a rate of 4 Hz or higher.

i) Resolver position data output from platform software **should (2)** be output at a rate of 10 Hz or higher.

j) Resolver position data output from platform software **should (3)** be output at a rate of 30 Hz or higher.

k) The delay from resolver position sampling to data output from platform software **should (2)** not exceed 10 ms.

2.4. Operational performance

a) Platform **should (1)** include LOS steering to a fixed set of guidance system provided pitch and azimuth angles <u>relative to pod centreline</u> regardless of aircraft manoeuvres, and stabilise angular noise in both axes. Described as "*MODE 1 – stabilise position referenced to pod centreline*" in chapter 1.4.

b) Platform **should (1)** include LOS steering to a set of guidance system provided pitch/azimuth angles <u>relative to earth</u> regardless of aircraft manoeuvres, and stabilise angular noise in both axes. Described as "*MODE 2 – stabilise position referenced to earth*" in chapter 1.4.

c) Platform **shall** include mechanisms to prevent damage due to free-floating platform when electrical power is not provided, described as "*MODE 3 – power off*" in chapter 1.4.

d) Mechanisms to prevent damage due to free-floating platform when electrical power is not provided **should (1)** be automatic and not require physical access to the platform.

e) Platform **should (1)** have a defined limit of LOS envelope with a buffer close to physical limit of movement (and mechanical constraints) allowing free movement for stabilisation of vibrations, as explained in Figure 1.2. Measurements during flights show angular vibration noise at platform position to be 0.44° (5 σ value).

f) The platform defined limit of LOS envelope **should (2)** be software configurable. (e.g. a lens change can possibly restrict the envelope due to mechanical restrictions.)

g) The platform defined limit of LOS envelope **should (3)** be in the shape of a trapezium, as physically limiting restrictions might vary with pitch angle.

h) Platform **should (1)**, when receiving a LOS command from guidance system or calculating a target position due to aircraft manoeuvres that is outside defined limit of movement, calculate new platform position to be at the defined limit of LOS envelope on a line between {0°,0°} (straight forward) and LOS command / target position, as illustrated in Figure 2.2. This "busy wait" platform position must be updated upon receiving new LOS command or when updated target position is calculated.

i) Azimuth axis **shall** have defined limit of LOS envelope greater than -5° to 5°.

j) Azimuth axis **should (1)** have defined limit of movement greater than -10° to 10°.

k) Pitch axis **shall** have defined limit of LOS envelope greater than 0° to -5° (LOS straight level to 5° pitching down).

l) Pitch axis **should(1)** have defined limit of LOS envelope greater than 0° to -15° (LOS straight level to 15° pitching down).

m) The platform pitch and azimuth axis angular rate of movement (slew rate) with a payload of 15kg **should (1)** be greater than 15°/s.

n) The platform pitch and azimuth axis angular rate of movement (slew rate) with a payload of 15kg **should (2)** be greater than 30°/s.

o) The accuracy of the resolvers and any motion sensors **should (1)** be less than 50 µrad.

p) The accuracy of the resolvers and any motion sensors **should (2)** be less than 10 µrad.

q) The platform stabilization accuracy **should (1)** be better than 100 µrad during operation environment described in chapter 1.2 and appendix A.

r) The platform stabilization accuracy **should (2)** be better than 20 µrad during operation environment described in chapter 1.2 and appendix A.

2.5. Additional equipment

a) The platform **should (2)** be delivered with necessary equipment for balancing the payload.

b) The platform **should (2)** be delivered with all necessary cables.

c) The platform **should (2)** be delivery as a "plug-and-play" system. This includes an interface computer running GUI software for control of platform settings, test procedures, performance analysis, and platform data storage. User friendliness of

GUI software and high level of software functionality is favoured.

2.6. Testing, documentation, training and support

a) Upon delivery there **shall** be performed a system acceptance test (SAT) with payload to verify requirements are met.

b) The payload can be provided for integration to the platform a limited time period before SAT, and the offer **should (2)** state the required duration of this period.

c) The offer **should (2)** include a training course for up to 5 persons (two days minimum) where the following topics are covered:
- Platform functional description
- Interfacing the platform system
- Platform software interface
- Platform balancing procedures
- General use, care and maintenance

d) The offer **should (1)** include details about warranty, product support (including pricing and response time to support requests).

e) The offer **should (2)** include expected MTBF for critical system components.

f) Platform **should (1)** be supported by the contractor for a minimum of 5 years.

g) Platform **should (2)** be supported by the contractor for a minimum of 10 years.

h) Dimensional drawings (including centre of pitch and azimuth axis, weight and centre of gravity) **should (1)** be included in the offer.

i) All user manuals **should (2)** be made available to purchaser as soon as possible and at the latest upon delivery.

j) Electrical specifications and software interface description (data communication protocols, etc) **should (1)** be made available to purchaser as soon as possible and at the latest upon delivery.

k) Tenderer **should (1)** in the offer specify environmental operating and non-operating conditions covering at least:
- vibrations
- mechanical shock
- temperature
- humidity
- air pressure

l) Documentation for certification purposes **should (1)** be delivered with the platform covering the following topics:
- Risk and consequence for fire
- Battery documentation to be approved by RNoAF (if platform contains batteries)

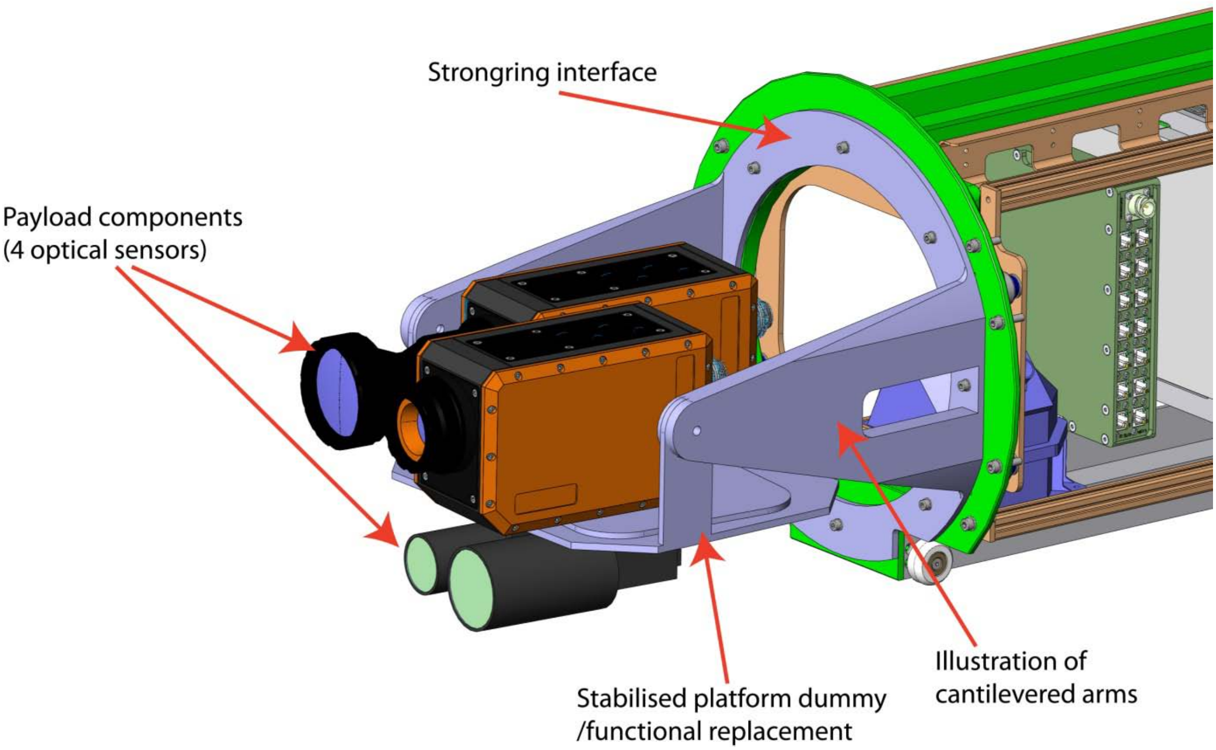

Figure 2.1 Dummy stabilised platform with payload.

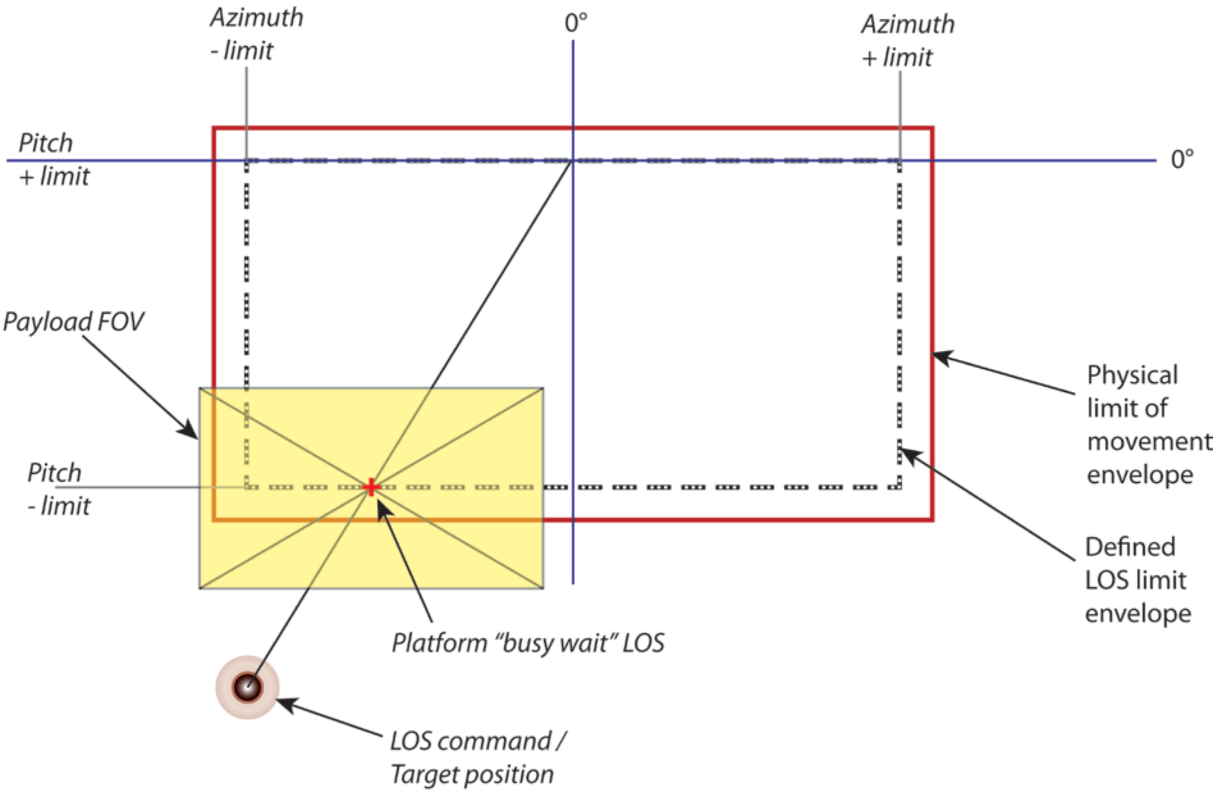

Figure 2.2 Platform LOS "busy wait" behaviour. Upon receiving a LOS-command or calculating a target position outside defined limit of LOS envelope, the platform shall "wait" at the crossing point between the defined limit of LOS envelope and a straight line between (0°,0°) and LOS command / target position.

Appendix A Lateral and vertical vibration environment

Measured Y-axis (lateral) vibration levels at platform position are presented in figure A.1, and measured Z-axis (vertical) vibrations are presented in figure A.2. These vibration levels occur at a distance of 1.3m in front of centre of pod, and will impose angular vibration noise that the platform of this procurement shall stabilise.

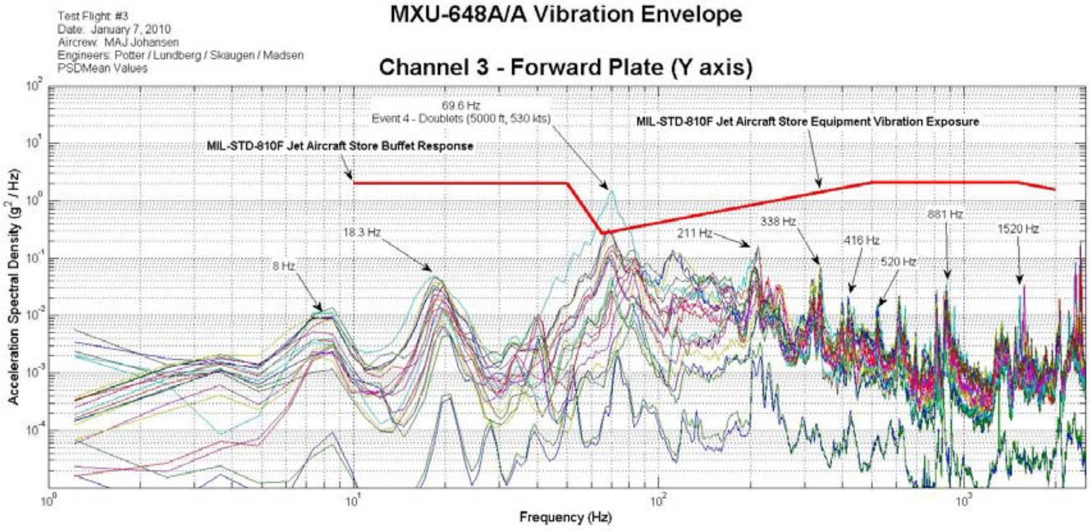

Figure A.1 Lateral (azimuth) vibrations at MXU-648 nose section. Each line i diagram represents a specific manoeuvre.

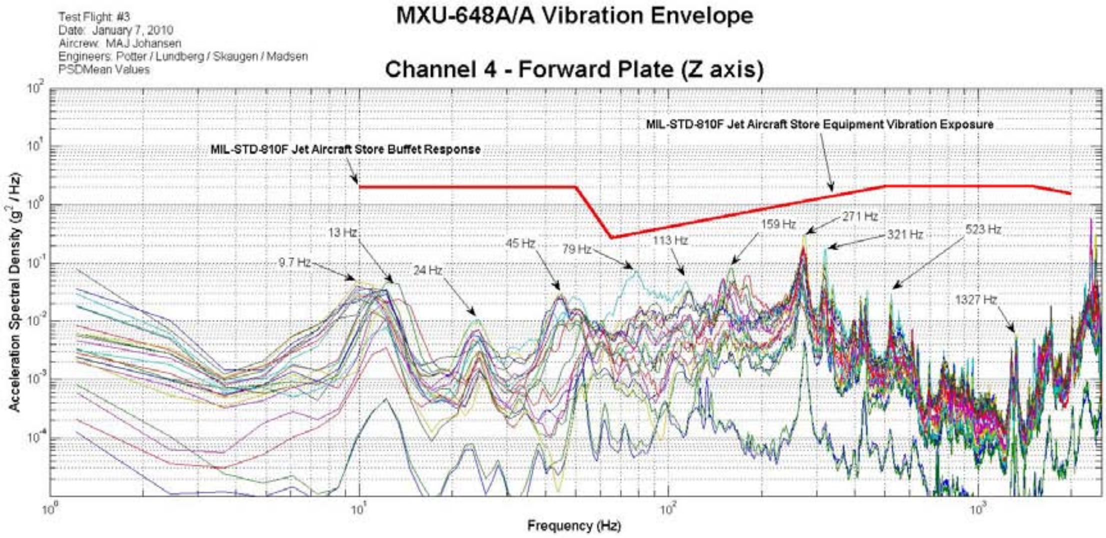

Figure A.2 Vertical (pitch) vibrations at MXU-648 nose section. Each line in diagram represents a specific manoeuvre.

Appendix B Platform volume

The platform has a restricted volume, and shall not extend outside the mechanical outline illustrated in Figure B.1. The only exception being payload components. Details of the platform volume and centre position of pitch and azimuth axis are given in Figure B.2.

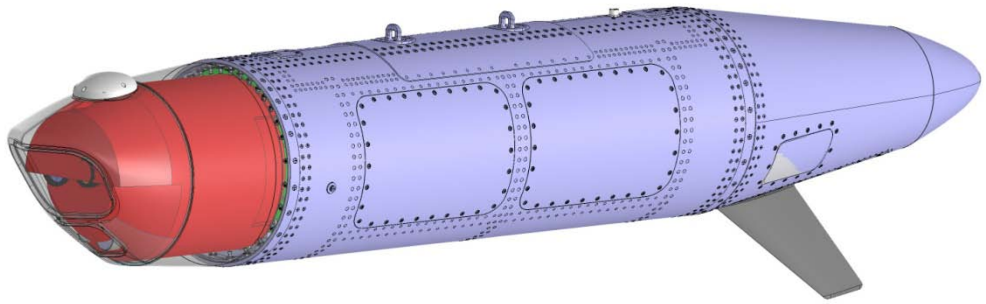

Figure B.1 Stabilised platform mechanical bounds / size limits shown in red. Payload components may extend out of these bounds (as shown in figure).

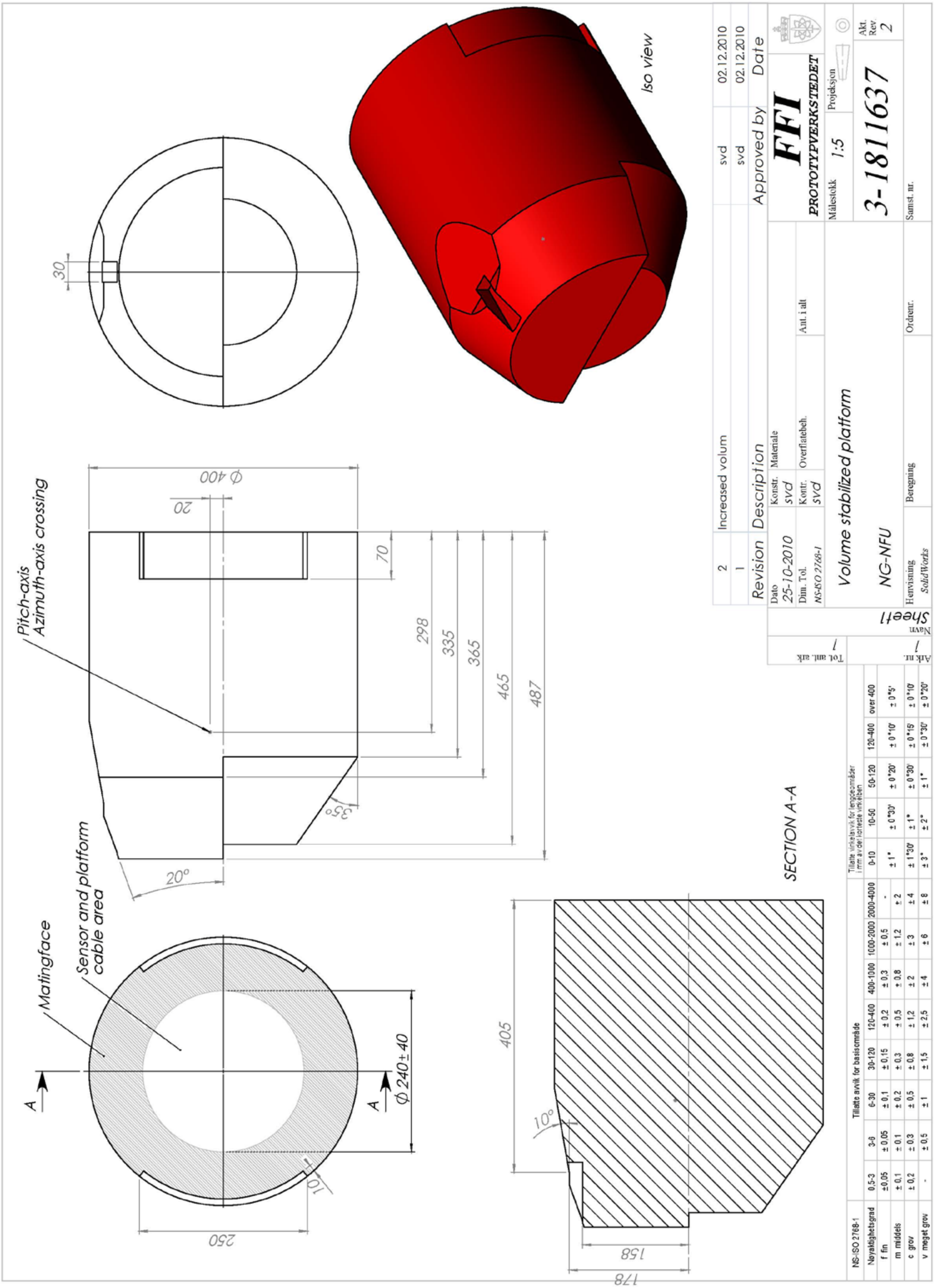

Figure B.2 Stabilised platform volume specifications.

Appendix C Load factors and angular accelerations

The loads affecting the platform are transferred from the aircraft wing, through the pod structure and cantilevered arms into the platform. The direction and magnitudes of the loads are taken from the MIL-STD 8591 Appendix A - without carrier catapult and arrested landing - and Appendix B for land barrier engagement. The orientations of loads are given using the coordinate system illustrated in Figure C.1.

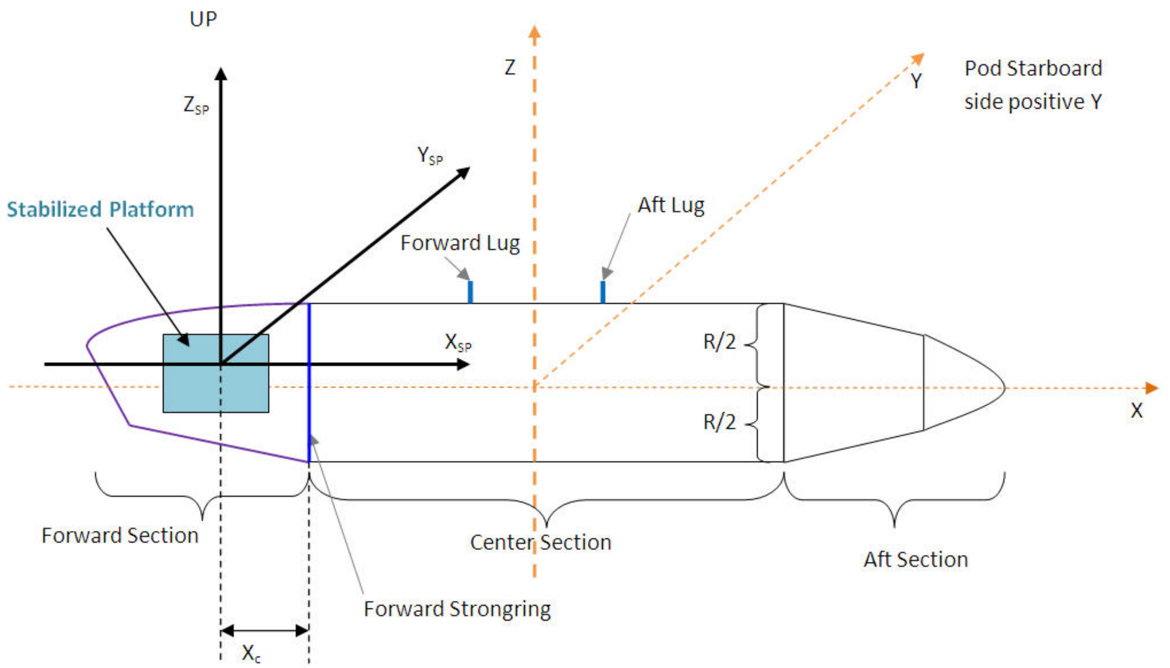

Figure C.1 Definition of store fixed axis system XYZ and stabilised platform axis system $(XYZ)_{SP}$. Origin of $(XYZ)_{SP}$ is located in the centre of gravity of the stabilised platform including payload.

The stabilised platform will be attached to the forward strongring through cantilevered arms. The distance between stabilised platform centre of gravity $(XYZ)_{SP}$ and forward strong ring, X_C, will depend on final mass and shape of the platform.

The load factors and angular accelerations are given in Table C.1. The loads factors in the table are equal in magnitude but opposite in direction to the accelerations.

Table C.1 Limited load factors and angular accelerations are given at centre og gravity of the stabilised platform $(XYZ)_{SP}$

	Load Factors			Angular accelerations		
	n_x	n_y	n_z	ω_X [rad/s^2]	ω_Y [rad/s^2]	ω_Z [rad/s^2]
Max positive	**6.4 g**	**9.5 g**	**13.6 g**	±60.0	±45.0	±20.0
Max negative	**-6.4 g**	**-9.5 g**	**-22.6 g**	±60.0	±45.0	±20.0

Load factor examples:

- n_x=6.4 g and m_{SP} (mass of stabilised platform inclusive sensors in kg) will give the following inertial force in the x-direction: F_x= 6.4·9.81 m/s^2 ·m_{SP} = 63 · m_{SP} [N]. Note this transverse force will push the stabilised platform aft (positive X-direction in Figure C.1)
- n_y=9.5 g gives the following inertial force in y-direction: F_y=9.5 ·9.81· m_{SP} = 93 · m_{SP} [N]. This force will push the stabilised platform towards the starboard side (positive Y - direction)

- n_z=-22 g's gives the following inertial force in z-direction: $F_z=-22 \cdot 9.81 \cdot m_{SP} = -216 \cdot m_{SP}$ [N]. This force will push the stabilised platform down (negative Z-direction)
- Both maximum and minimum load factors shall be considered for the integrity of the stabilised platform during the design.

Mass inertial (CG stabilised platform) I_{yy} and I_{zz} will most likely be less than 0.1 kgm^2. For the given angular acceleration levels the inertial moments from the angular accelerations will be negligible compared to the loads from the translational accelerations (given as load factors). Therefore angular accelerations in Table C.1 do not have to be considered in the mechanical design of the stabilised platform.

Appendix D Payload description

The payload will consist of up to four forward-looking optical sensors. The number of sensors and their weight and shape will vary during the lifespan of the pod system. Initial configuration will include a collection of sensors as shown in Figure 2.1 and listed in Table D.1. The total payload weight of the initial payload configuration could be close to 15 kg, not including necessary brackets and fasteners.

Table D.1 List of initial platform payload sensors.

Sensor	Width	Height	Length	Weight
IR-camera MW	110 mm	140 mm	220 mm + optics and connectors	3-5 kg (optics dependent)
IR-camera LW	110 mm	140 mm	220 mm + optics and connectors	3-5 kg (optics dependent)
Video camera	70 mm	70 mm	170 mm + connectors	0.5-2.5 kg
IR-camera SW	53 mm	53 mm	150mm + connectors	0.8-2.5 kg

The optics may change between field trials, but sensor changes are less frequent. Figure D.1 shows the MWIR and LWIR cameras with the different optics available today. These two cameras are the largest sensors of the system, and dictate the required platform room available for the payload.

Figure D.1 IR-cameras with alternative optics. Top: LWIR with 100mm (left) and LWIR with 50mm (right). Bottom: MWIR with 100 mm (left) and MWIR with 50 mm (right). (Not more than two of these cameras will be used as part of the payload at any time.)

The LWIR camera with 100 mm optics is also shown in Figure D.2, Figure D.3 and Figure D.4.

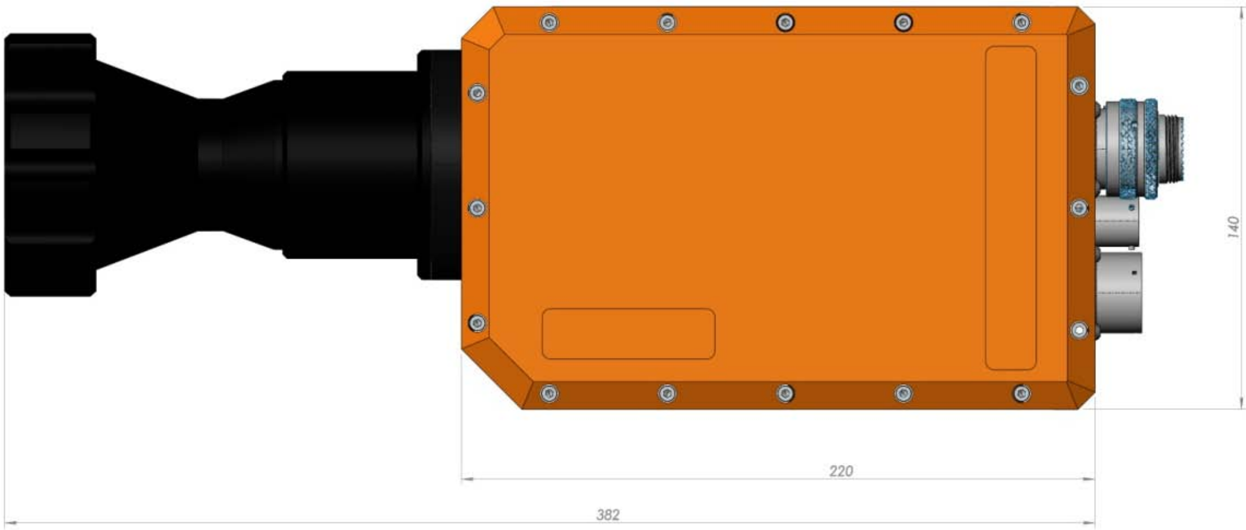

Figure D.2 LWIR camera with 100 mm optics, side view.

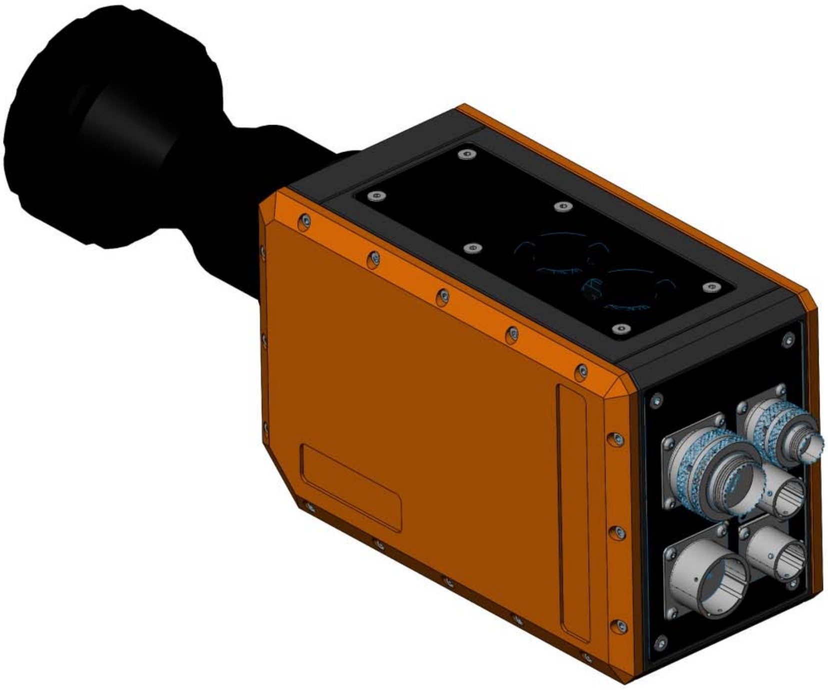

Figure D.3 LWIR camera with 100 mm optics, aft view.

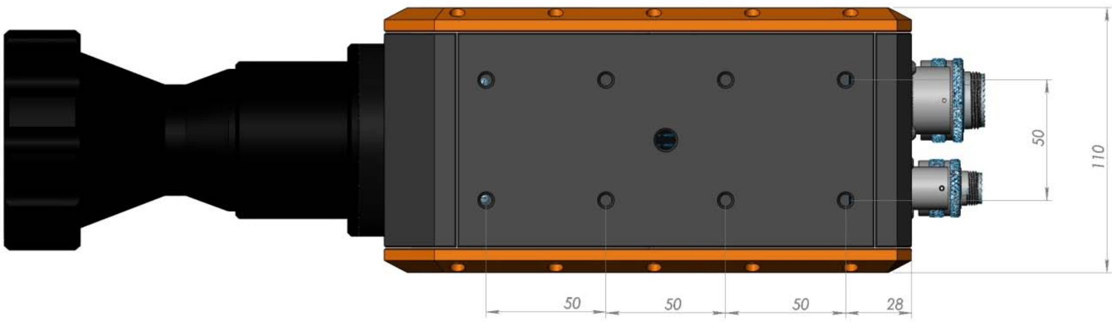

Figure D.4 LWIR camera with 100 mm optics, bottom view.

Figure D.5 shows the initial payload configuration from Table D.1 with measures for the required payload area of the platform.

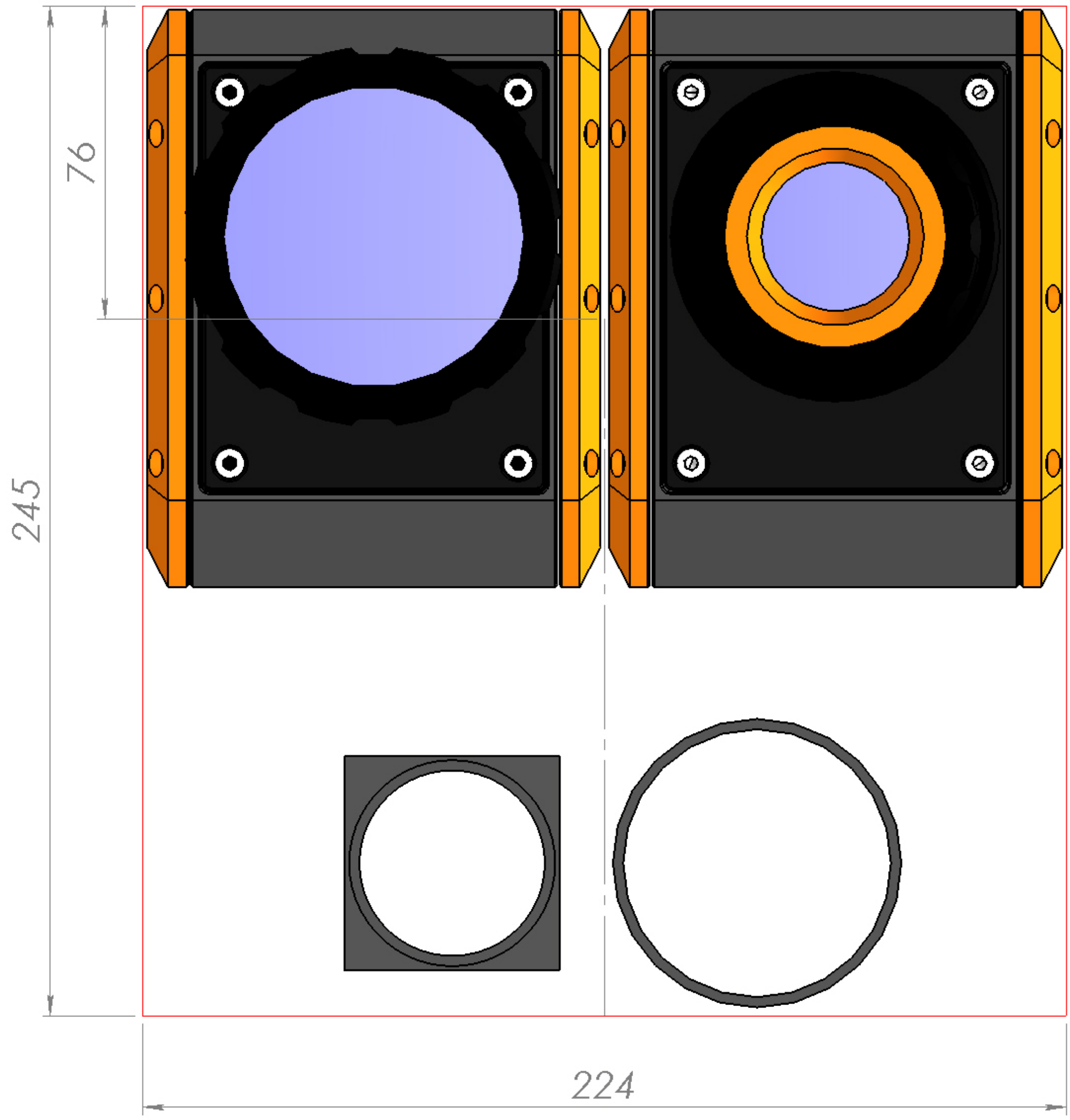

Figure D.5 **Initial payload configuration front view with measures for minimum required platform payload area. The centre of the pitch axis is marked as 76 mm below the top.**