ESA NAVISP ICING – Independent Critical Navigation

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Sven.Ingve.Rasmussen@Spacenorway.no

SPACE NORWAY

KONGSBERG

Agenda

- Background
  - National Contex
  - Consortium
  - NorSat-TD
- The ICING Project
- Technical concept
- Progress
- Way forward

Rationale and Background

- The maritime industry is dependent on available and timely delivery of Position, Navigation and Timing (PNT) information;
- PNT information is derived from weak GNSS satellite signals, vulnerable to disturbances (unintentional or intentional);
- A loss of GNSS signal could compromise the ship electronic charting systems (ECDIS), the automatic identification systems (AIS) used for ship collision avoidance and onboard GPS receivers;
- Intentional disturbance of GNSS signals are seen utilized in situations of conflict, during illegal fishing operations and as a counter-security measure;
- Maritime digitalization and autonomous shipping operations are driving the need for contingency systems available to provide timely PNT information.

Relevance in national context

- Timely provision of PNT information is essential to several operations in the northern region of Norway:
  - Navigation at sea;
  - Search & rescue operations;
  - Medical evacuation and transportation by helicopter;
  - Air traffic control;
- Loss of GNSS signal will either suspend, jeopardize or significantly delay these operations and services.
- Norway is experiencing an increasing amount of disturbances to the GNSS signals available:
  - 2017: signal lost over Finmark several times during one week
  - 2018: GNSS network in northern Norway blocked 3 times (2-3 weeks each time), during NATO-exercise Trident Juncture
  - 2018: National Air Ambulance Services of Norway experienced 19 losses of signal
  - 2019: GNSS disturbances recorded by air traffic operators in both Tromsø and Bodø
  - 2019: National Air Ambulance Services of Norway experienced 10 losses of signal until 31st March
- Norwegian intelligence services expects a further increase in GNSS signal disturbances in coming years.
  - The Director of the Joint Rescue Coordination Centre in Northern Norway fears that loss of PNT information will lead to delayed rescue operations;
  - The former Minister of Defense Bakke-Jensen said “Norway’s protection against GPS jamming is to have alternative ways to navigate”

ESA ICING project – Independent Critical Navigation

- The Consortium consist of Space Norway (SPN) and Kongsberg Seatex (KSX)
  - SPN is Prime, Design Authority and owner of VDE-SAT payload on NorSat-TD
  - Kongsberg Seatex delivers VDE-SAT payload and VDES terminals
- ESA funded project under the NAVISP Program to test a concept utilizing VDE-SAT VHF satellites to provide pseudo-range signals as a source of PNT.
- The new NorSat-TD offered the opportunity to quickly test the concept
  - SPN VDE-SAT payload synced directly to GNSS PPS
  - Maximum re-use of VDES infrastructure
  - No change to ITU approved VDES standard (ITU-R M.2092-1)
- Timing accuracy and jitter to be measured at one fixed locations in Norway, in addition the Ocean Spacelab Vessel at KSX will be used.
- A “new space” approach is used to minimize complexity, implementation time and costs.
- The aim is to achieve a first step towards a service with quality for potential maritime use.
- VDE-SAT ranging has a potential for complementing other platforms used for independent PNT such as Terrestrial R-mode.

NorSat-TD: Test platform for ICING

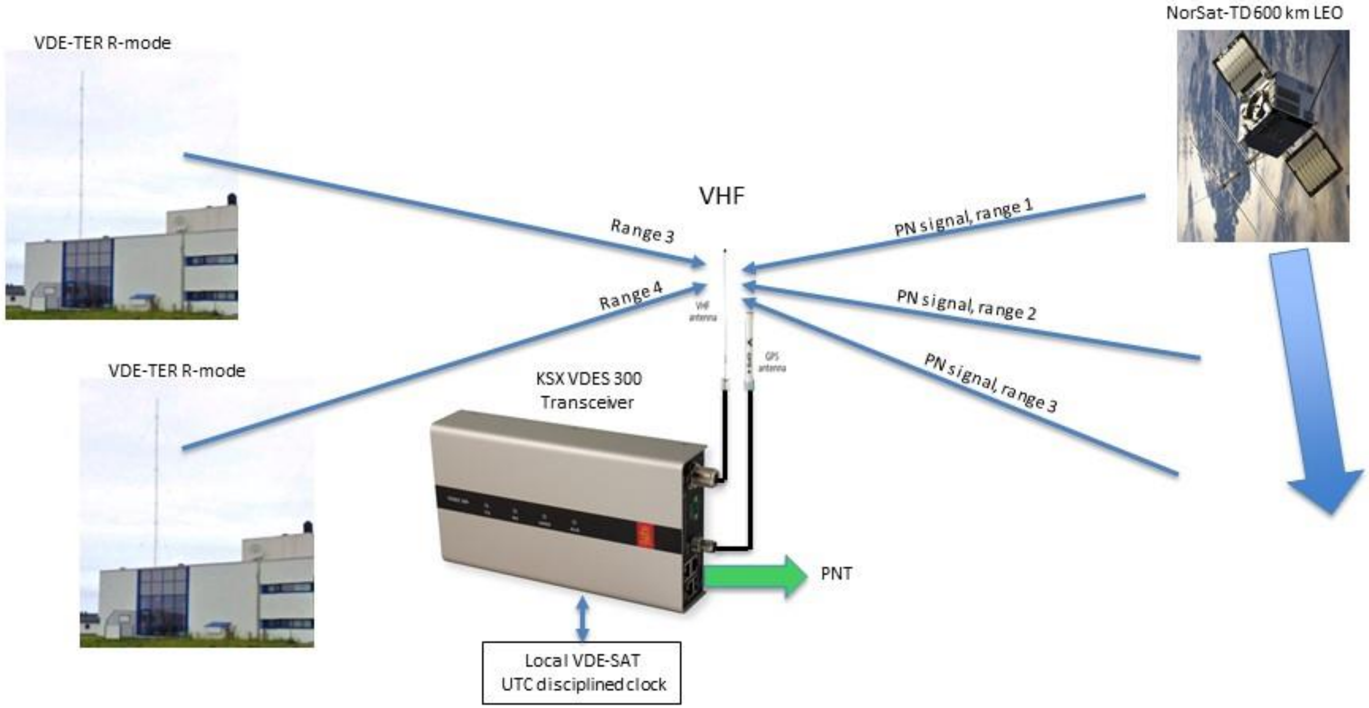
- NorSat-TD is a near identical satellite to NorSat-II. It is a test and demonstration platform.
- Owned by Norwegian Space Agency
- Test payloads financed by various companies
- Under construction by UTIAS, Defiant bus
- 525 km, 97 degrees inclined LEO
- Space-X launch February 2023
- Propulsion for orbit phasing
- SPN payloads
  - Similar VDES to NorSat-2 in use since 2017
  - SDR VDE-SAT transceiver developed by Kongsberg Seatex
  - Tightly synchronized to GNSS PPS clock
  - Linear 2 W transmitter at 157/162 MHz
  - 8 dBi deployable RHCP Yagi limb pointing antenna, including inspection camera
  - 1 Mbps S-Band feeder links for F/W uploads
- Energy budget supports >30% orbit duty-cycle

Technical concept: VDE-SAT Precision Time Broadcast

- Broadcast 112.8 kcps VDES pseudo-range packet
  - UTC offset synched to GNSS PPS on satellite
  - Static content with acceptable autocorrelation
  - 269816 chips
  - 2.4 s duration
  - 1 minute interval
  - Around 47 dBHz median C/N0
  - Alternate transmissions at the carrier frequencies 157 and 162 MHz not considered worth while ($\Delta R < 160$ m)
  - Target pseudo range jitter < 300 m
- Broadcast VDES navigation data packet
  - 35 bytes pay net load
  - Satellite position with raw data in X,Y,Z coordinates
  - UTC time offset
  - Auxiliary data such as propagation information
  - Three repeats to overcome deep fades
- Measure multiple pseudo ranges during pass to obtain PNT
- Uses 6.5 % of VDE-SAT capacity
- Discipline local UTC clock and keep drift below +/- 10 ppb/hr using TCXOs.
- Provide real time PNT with two additional VDE-TER R-mode transmitters per service area
- Low cost VDES transceiver and antennas with TCXO and software upgrades on ships
- Low cost VDES reference stations foreseen for propagation corrections
- Additional VDE-SAT application on existing infrastructure

VDE-SAT Precision Time Broadcasting

Kongsberg Seatex



Navisp ICING project

European Space Agency

Use VDES allocated VHF frequencies

- 157 and 162 MHz allocated at WRC-19
- Available from 2021, but requires national clearing, started in Norway, experimental use already allowed
- Standard defined in ITU-R M.2092-(1)
- ITU approval entered into force 23.2.2022
- New specialized waveform for navigation would be long process
- Icing project uses existing 141 kHz wide waveform with static content
- Nominally broadcasted every 1-minute frame
- Dynamic navigation data (NAVDAT) broadcasted as standard message on 50 kHz channel, repeated three times to handle fading

VDES Icing ranging waveform (LID 29)

Link ID 29
Static content
BPSK
112.8 kcps
2392 ms duration
269816 chips

Link ID	25	26	27	28	29	30	31	
Channel BW	50			100	150	300	500	kHz
Roll off filtering	0,25							
Signal BW	42,0			90,0	141	291,0	492	kHz
CDMA chiprate	33,6			72,0	112,8	232,8	393,6	kcps
Codelength	8			2				chips
Symbol rate	4,2	33,6		36,0	56,4	116,4	196,8	ksps
Burst size	90							slots
Guard time	8							ms
Burst duration	2392,0							ms
Symbols/burst	10046	80371		86112	134908	278428	470745	symbols
Ramp-up/down	14/14			30/30	47/47	96/96	162/162	symbols / chips
Ramp-up/down	0.41/0.41							ms
Syncword size	48	27		48				symbols
Number of syncwords	10	35		32				
Total syncword symbols	480	945		1536				symbols
Syncword distance	1004	2268		2690	4214	8697	14705	symbols
Syncword modulation	BPSK/ CDMA	PI/4 QPSK (00 /11)		BPSK/CDMA				
Link Config ID	0 (not used)							symbols
Link Config ID modulation	BPSK/ CDMA	PI/4 QPSK		BPSK/CDMA				
Pilot distance		27						symbols
Total pilots symbols		2940						symbols
Net symbols/burst	9562	76458	76458	84546	133325	276796	469047	symbols
Burst stuffing bits	0	1	6	2	5	0	7	bits
Channel bits	9562	152915	229368	84544	133320	276796	469040	bits
Padding + FEC tail***	0+10	7*(3+18)	(0+8)*19	4*(0+16)	6*(0+12)	13*(0+12)	22*(0+8)	bits
FEC decoder input symbols	9552	76384	76406	84480	133248	276640	468864	symbols
FEC decoder input bits*	9552	152768	229216	84480	133248	276640	468864	bits
FEC output bits	4776	7*5456	19*6032	4*5280	6*5552	13*5320	22*5328	bits
FEC output	597	7*682	19*754	4*660	6*694	13*665	22*666	bytes
FEC sub-blocks	1	7	19	4	6	13	22	
Modulation	BPSK/ CDMA	PI/4 QPSK	8PSK	BPSK/CDMA				
FEC rate	1/2	1/4	1/2	1/4				
E_s/N_0 on AWGN	-2,0	-2,4	5,0	-2,0				dB
$C/(N_0+I_0)$ thres	34,2	42,9	50,3	40,6	42,5	45,6	47,9	dBHz

VDES Icing NAV message waveform (LID 32)

Link ID 32
Gross payload 39 bytes
Net payload 35 bytes
Threshold 32.4 dBHz
Nominal fade margin 10 dB

Link ID	32	33	34	
Channel BW	50			kHz
Roll off filtering	0,25			
Signal BW	42,0			kHz
CDMA chiprate	33,6			kcps
Codelength	8			chips
Symbol rate	4,2	33,6		ksps
Burst size	15			slots
Guard time	8			ms
Burst duration	392,0			ms
Symbols/burst	1646	13171		symbols
Ramp-up/down	14/14			symbols/chips
Ramp-up/down	0.41/0.41			ms
Syncword size	48	48	27	symbols
Number of syncwords	4	6	6	symbols
Total syncword symbols	192	288	162	symbols
Syncword distance	531	2619	2619	symbols
Syncword modulation	BPSK / CDMA	BPSK	PI/4-QPSK (00 /11)	
Pilot distance	8		27	symbols
Total pilots symbols	180		480	symbols
Burst symbol duration*	1641	13143	13122	symbols
Net symbols/burst	1269	12855	12480	symbols
Channel bits	1269	12855	24960	bits
Padding + FEC tail ***	0+21	0+15	0+0	bits
FEC decoder input symbols	1248	12840	12480	symbols
FEC decoder input bits	1248	12840	2*12480	bits
FEC output bits	312	4280	2*4160	bits
FEC output	39	535	1040	bytes
Modulation	BPSK/CDMA	BPSK	PI/4 QPSK	
FEC rate	1/4	1/3	1/3	
E_s/N_0 on AWGN	-4,5	-3,6	-0,6	dB
Minimum CQI value	21	24	36	

Icing Nav message v1 content

Field No	Name	Bytes	Description
1	Message ID	1	203
2	Position data	10	Earth Centric coordinates X, Y, Z
3	Speed over ground	2	Satellite velocity over ground in km/s (as v*5)
4	Course over ground	2	Satellite course over ground in degrees heading (as degrees*10)
5	UTC time	4	Time at epoch as number of seconds since 1st January 2000 at 12:00 UTC
6	Tx timing offset	2	Transmitter timing offset from slot boundary (ns)
7	Atmospheric vertical delays	2	Estimated-vertical atmospheric delays at tx frequency(us)
8	Slot number	2	VDES slot number (0-2249) at which the range message was sent, slots start at minute epoch–2000 us
9	Frame number	2	Frame number (UTC minute modulo 216) at which the range message was sent.
10	Spare	7	Reserved for future use

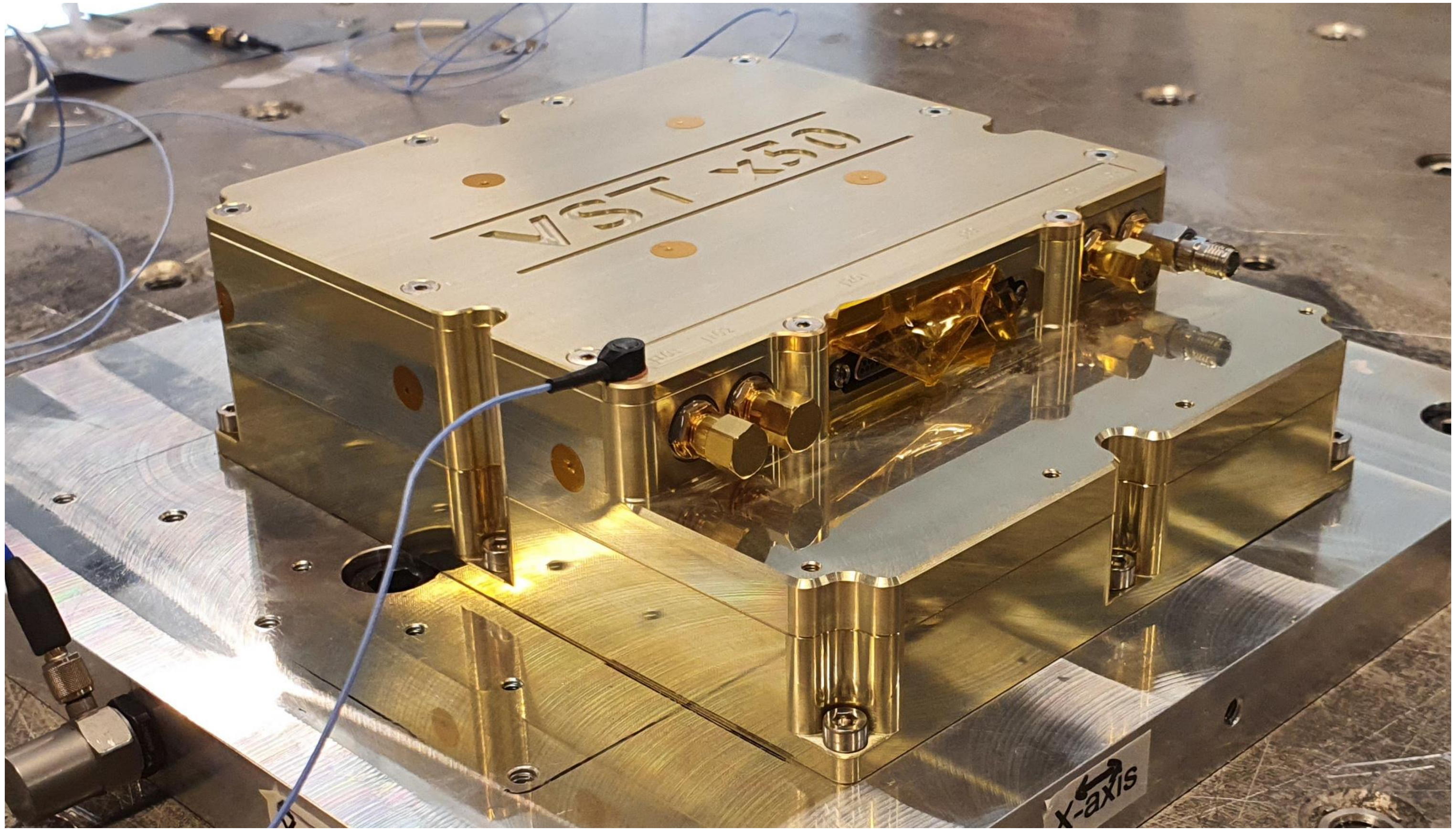
Performance expectations

- Expected TOA accuracy within +/1 us RSS, excluding propagation
- Sufficient for proof of concept.
- Dual frequency 157/162 MHz operation not planned because range variation with expected Tcount is 160 m, less than measurement accuracy
- Navigation message has spare fields, and may be modified if required
- Main uncertainty is caused by propagation:
  - Specular multipath causes fading and near-in correlation sidelobes
  - Ionospheric delay variations over area not known (to us)

- Test results expected to provide more information
  - Improvement areas
  - Ionospheric delays (temporal and area variations)
  - Service provision to be decided (Public or VDES Precision Time Service)

Progress: VDES Payload

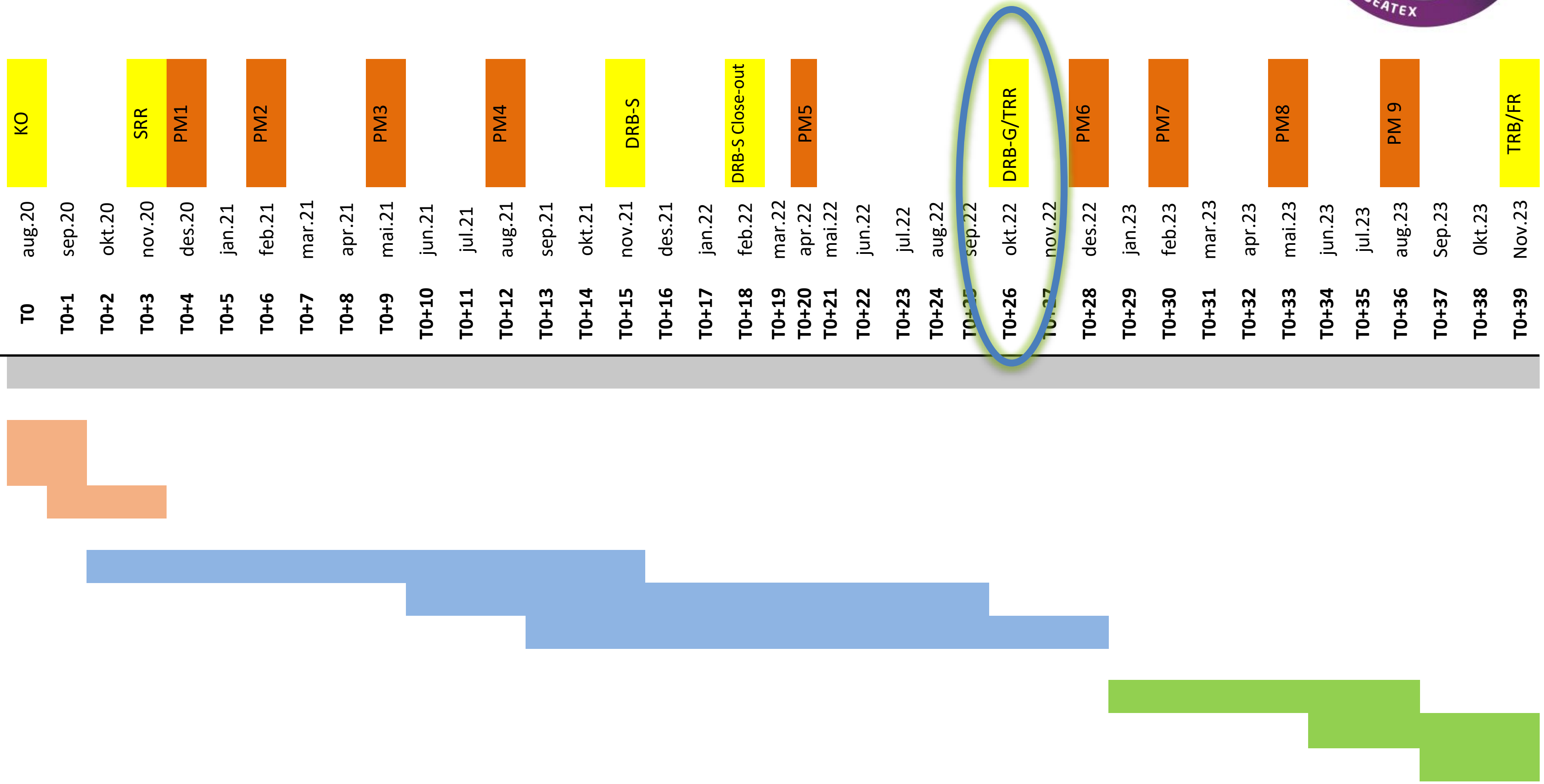
- VDES Payload (VST x50) delivered by KSX and fully integrated into NorSat-TD, both engineering model and flight model.
- Hardware and firmware modifications are completed to fully support the ICING functionality.



Schedule & Milestones

Milestones

Dates



WP	WP Title
WP1000	Project management
WP2100	System modelling
WP2200	Requirements analysis
WP2300	System specification
WP3100	Space infrastructure
WP3200	Ground infrastructure
WP3300	Test planning
WP4100	Test campaign
WP4200	Test analysis & reporting
WP4300	User assessment & future recommendations

Timeline ICING and Norsat-TD

NorSat-TD:

Feb-Oct-> Flat-Sat testing

Aug-Oct -> T-VAC testing

Dec -> Transportation from UTIAS to launch site.

Feb 2023 -> Launch

Feb - Mar 2023 -> Commissioning

ICING:

Sep/Oct 2022 -> DRB-G for ground infrastructure + Test Readiness Review

Mar.2023 - Aug. 2023 -> Test Campaign

Aug. 2023 - Oct. 2023 -> Analysis & Reporting

Nov. 2023 -> Test Review Board / Final Review