Pointing Error Engineering Evolutions: Overview for SAVOIR Advisory Group

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Agenda

1. Pointing Error Engineering: Framework & Evolutions overview

2. Pointing Error Engineering Handbook update:
    - Introduction: Pointing Error Engineering Process recalled
    - Reasons for the update
    - Summary of the upgrades
    - Schedule for the release

3. New ESA Pointing Error Mapping Handbook:
    - Objectives and Use
    - Content overview
    - Use in corpus ECSS/Handbooks
    - Schedule for the release

1. Pointing Error Engineering: Framework

- Pointing Error Engineering: **Specifying and budgeting pointing performance & knowledge**

- **Key documents on Pointing Error Engineering used on ESA projects**
  at Mission System Requirements Document (SRD) level:
  - ECSS-E-ST-60-10C - **ECSS Space engineering - Control performance standard:** issue 1 from 2008
    - ➔ Used as **Applicable & Normative** document
    - ➔ Provides definitions, methods & rules for specifying, budgeting & verifying performance and for validation
  - ESSB-HB-E-003 - **ESA Pointing Error Engineering Handbook:** issue 1 from 2011
    - ➔ Used as **Applicable / Reference** document
    - ➔ Provides guidelines for applying the ECSS: step by step process mathematically based

- A useful link: The PEET ESA website includes most of the relevant information on Pointing error engineering (with ECSS and PEEH download links): http://peet.estec.esa.int/

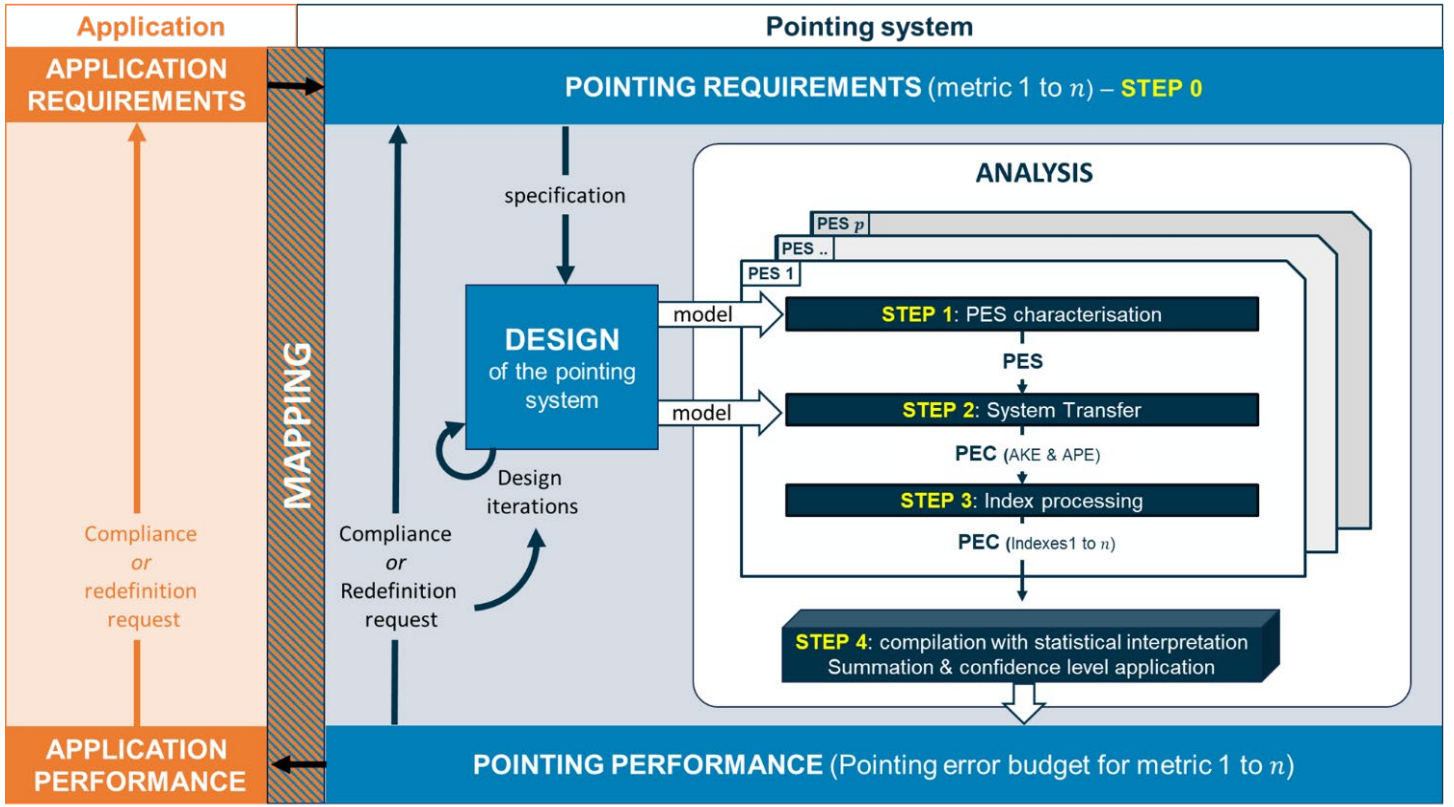
1. Pointing Error Engineering: Evolutions overview

- Imminent evolutions:
  - The **update & major upgrade** of the ESA **Pointing Error Engineering Handbook** (ESSB-HB-E-003)
    - ➔ See next slides
  - The **new Pointing Error Mapping Handbook** (ESSB-HB-E-004)
    - ➔ See next slides

- Foreseen future evolutions linked to Pointing Error Engineering (**TBC**):
  - Harmonization of the **ECSS Space engineering - Control performance standard** (ECSS-E-ST-60-10C)
    - ➔ **To include normative content** from **Pointing Error Engineering Handbook**
  - Harmonization and merging of the **ECSS E-60 and ESA handbooks**

2. Pointing Error Engineering Handbook update: Intro

- Pointing Error Engineering Process recalled:
  - It starts with the **Definition of the Pointing Error Requirements** with Step 0 (see next slides)
  - Then the **Evaluation of the performance / knowledge budgets** is a 4-steps process:
    1. Pointing Error Source characterization
    2. System Transfer
    3. Index processing
    4. Budget compilation



2. Pointing Error Engineering Handbook update: Reasons

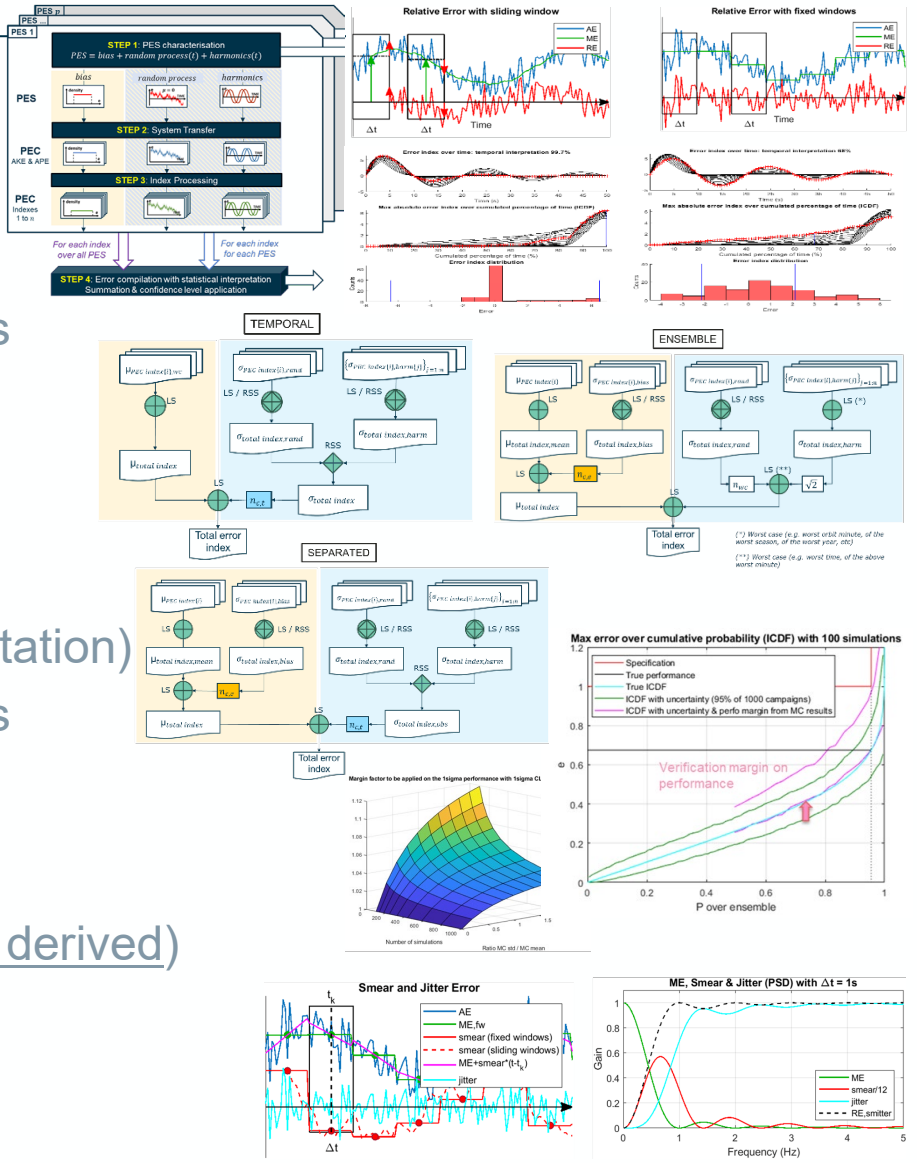
- **Lack of clarity to be mitigated**:
  - To enable **improved understanding between all parties** (System, PF, PL, different disciplines)
  - To ensure **easier adoption & implementation**

- **Lessons learned** to be implemented: some examples
  - Statistics processing (statistical interpretation) for accurate performance assessment
  - Relative Pointing Error definition to always cover drift effects
  - Performance campaign (Monte-Carlo simulations) with guaranteed performance (while avoiding huge number of simulations)

- **Specific mission needs** to be addressed:
  - Introduction of new error indexes

2. Pointing Error Engineering Handbook: Upgrades

- **Lack of clarity mitigated** ✅
  - Step 0: Clear list of aspects to define a requirement
  - Step 1: Streamlined overall process & error characterization
  - Step 3: Consistent definitions of indexes with explanatory figures
  - Step 4: Clear process for statistical interpretation application, clear summation rules for simplified method
- **Lessons learned implemented** ✅
  - Step 0: New separate interpretation (~ relaxed temporal interpretation) Mixed interpretation to be avoided, additional ensemble domains
  - Step 3: Updated Relative Pointing Error definitions covering drift
  - Step 4: Verification margin introduced, **new** recommended number of simulations (both mathematically derived)
- **Specific mission needs addressed** ✅
  - Step 3: New error indexes (RPEedge: error distribution with fast processing, smear, jitter)



2. Pointing Error Engineering Handbook: Call for feedback

- **Mid-October 2024** **SAVOIR SAG to provide points of contact**
  for receiving updated PEEH for comments

➔ As ESA handbook, the approval loop is ESA internal (different from ECSS)

➔ However, in view streamlining of ECSS E-60 Standards and Handbooks,
it is helpful to have discussions on this updated version

3. New ESA Pointing Error Mapping Handbook: Objectives

- **Context**:
  ECSS E-60 & ESA PEEH incomplete to help System Managers in Phase 0/A:
  Missing mapping step to go from mission requirements to pointing requirements

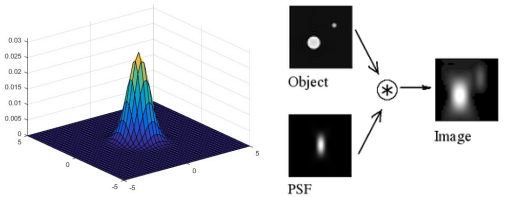
- **Objectives for this new handbook:**
  - Providing **guidelines for the flow-down of missions' requirements** to pointing requirements
  - Additional objective: provide a summary of PEEH (especially for specifying pointing requirements)
  ➔ pushed streamlined and clearer process in the PEEH (done with its own update)

- **Current & future use:**
  ➔ Use as **reference** document in Missions SRD in Phase 0/A

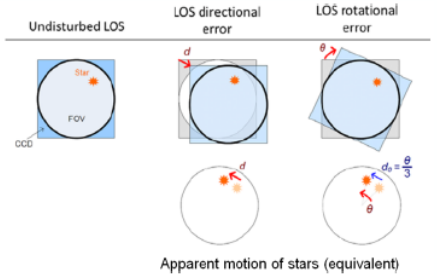
3. New ESA Pointing Error Mapping Handbook: Overview

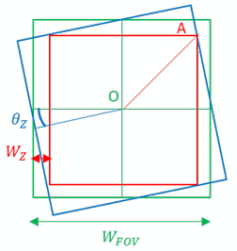
- Introduction to Error Budget Engineering
  - Summary of PEEH on key definitions & specification aspects
- Mapping typical requirements to pointing indexes
- General approach for flow-down of requirements
- Flow-down methods for typical requirements (computing specification value)
- Annex with definitions, relevant formulas & flow-down mathematical derivation

Mission needs: Related pointing indexes highlighted with X or with the letters related to the row items bullets	Applications		Usual flow down to pointing indexes					
	Earth Observation	Science	APE/ MPE	RPE	PDE	AKE/ MKE	RKE	KDE
Targeting / single image coverage	Any instruments of any mission		X					
Multiple images / swaths coverage: Overlap between stares/swaths	Step & stare & continuous scanning instruments: *MTG-S IRS, MTG-I FCI*	Step & stare missions &scanning: *Euclid*	X	(X)	X			
Resolution / separation of objects with either: a. PSF enlargement by pointing / Pointing MTF / Pointing WFE b. Or PSF enlargement by post-accumulation of multiple images without co-registration knowledge correction c. Or Stability of Spatial Sampling Distance (SSD)	a. Any photometers, spectrometer, and imager: *CHIME* b. Any TDI instruments: *Pleiades* c. Any continuous scanning instruments as push-brooms with spined satellites, or scanning mechanism: *MTG-I FCI*	a. Any photometers, spectrometer, and imager: *Ariel* b. Any TDI instruments: *GaiaNIR*		a (b) (c)	(b) (c)			
Image Signal to Noise Ratio (SNR) & radiometry / photometry in single observation with both: d. PSF displacement e. And PSF enlargement / stability from pointing	Any radiometer, spectrometer: *MTG UVN*	Any photometers, radiometer, spectrometer, imager: *Ariel, Plato, Gaia, Euclid*	(d)	e	(d)			
Location of the images / measurements: f. Absolute g. Relative (to a given target)	Geo-location applications: a. Any instrument of any mission b. When calibration is considered	Astrometric accuracy applications: a. Any instrument of any mission b. When calibration is considered				f	(g)	(g)
Co-registration of: h. Different images / measurements from different instruments / spectral bands i. Multiple images of the same instrument for Image SNR with post-accumulation	a. Any of multiple instruments with merged data on the same satellite: Metop-SG instruments & 3MI bands, MTG-S IRS/UVN	a. Any of multiple instruments with merged data on same satellite: Ariel instruments b. Any instrument with post-accumulation on ground: Ariel, Vigil PMI				h	(i)	(i)

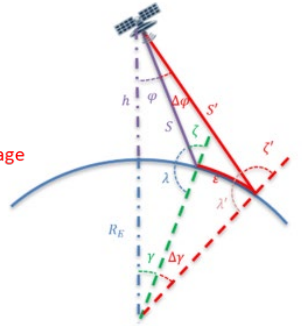


Type	Mission requirement & allocation	Type of pointing index	Pointing specification values	Inputs
General Image requirements	PSF Drift / Displacement: D_{spec}	PDE or smear / MPE	$\begin{bmatrix}\theta_X\\ \theta_Y\\ \theta_Z\end{bmatrix} = \begin{bmatrix}1&0&0\\0&1&0\\0&0&K\end{bmatrix}.\frac{\theta_{pixel}.D_{spec}}{\sqrt{2+K_N^2}}$	θ_{pixel} as pixel size K as Z pointing degradation with regard to X/Y $1/N$ as reduced impact of Z on displacement with regard to X/Y
	PSF enlargement: E_{spec} Leading to total RPE in pixels: $R_{spec} = k.E_{spec}$	RPE	$\begin{bmatrix}\theta_{RPE,X}\\ \theta_{RPE,Y}\\ \theta_{RPE,Z}\end{bmatrix} = \begin{bmatrix}1&0&0\\0&1&0\\0&0&K_{RPE}\end{bmatrix}.\frac{k.\theta_{pixel}.R_{spec}}{\sqrt{1+\left(K_{RPE}/_N\right)^2}}$	θ_{pixel} as pixel size k as factor between RPE specified value and pointing PSF specified value K_{RPE} as RPE Z degradation wrt. X/Y $1/N$ as reduced impact of Z on enlargement with regard to X/Y
	Angular overlap: W_{spec}	PDE X,Y & MPE Z	$\begin{bmatrix}\theta_{PDE,X}\\ \theta_{PDE,Y}\\ \theta_{MPE,Z}\end{bmatrix} = \begin{bmatrix}1&0&0\\0&1&0\\0&0&K_{PDE}\end{bmatrix}.\frac{W_{spec}}{1+K_{PDE}.W_{FOV}}$	W_{FOV} as angular FOV width K_{PDE} as factor of impact for Z mean pointing with regard to Drift on X/Y
EO requirements	Geolocation error: ε	AKE	$\theta = \Delta\varphi = \arcsin\left(\frac{R_E}{S'}\sin\left(\zeta - \varphi + \frac{\varepsilon}{R_E}\right)\right) - \varphi$ With $\varphi = \arcsin\left(\frac{R_E \sin\zeta}{R_E+h}\right)$ And $S' = \sqrt{(R_E+h)^2 + R_E^2 - 2R_E.(R_E+h).\cos\left(\zeta - \varphi + \frac{\varepsilon}{R_E}\right)}$	h as height RE as Earth radius φ as off-nadir angle ζ as off-zenith angle
	Off-zenith angle error: $\Delta\zeta$	APE	$\theta = \Delta\varphi = \arcsin\left(\frac{R_E \sin(\zeta + \Delta\zeta)}{R_E + h}\right) - \varphi$	h as height RE as Earth radius φ as off-nadir angle ζ as off-zenith angle
	Azimuth & elevation errors Δ_α & Δ_β	APE	$\begin{bmatrix}e_x\\ e_y\\ e_z\end{bmatrix} = \begin{bmatrix}\begin{bmatrix}1\\1\end{bmatrix}.\min\left(\frac{\Delta_\alpha}{\sqrt{K^2+\frac{1}{\tan^2(\beta)}}};\Delta_\beta\right)\\ \frac{K}{\sqrt{K^2+\frac{1}{\tan^2(\beta)}}}\end{bmatrix}$	β as off-nadir angle (average elevation) K as Z pointing degradation with regard to X/Y





Target FOV
Actual FOV
Worst case target coverage



3. New ESA Pointing Error Mapping Handbook: Schedule

- **October 2024** **Final draft**
- **Q4 2024** **Release of Issue 1**
- Feedback welcome through SAVOIR SAG

AOB

Any question or comment?