ADVIES 224
VLAAMSE PRIORITEITEN VOOR OPTIONELE ESA-PROGRAMMA'S - ESA-MINISTERRAAD 2016
13 OKTOBER 2016

VLAAMSE RAAD VOOR WETENSCHAP EN INNOVATIE

ADVIES 224

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INHOUDSTAFEL

EXECUTIVE SUMMARY

With this advisory report the Flemish Council for Science and Innovation wishes to contribute to the preparation of the commitments that Belgium will propose for the optional ESA programs at the ESA Ministerial Council meeting in December 2016. During this Ministerial Council meeting the optional programs for the coming years and the contributions of the ESA member states for these programs are determined. Member states base their contribution on the expertise present in their country.

ESA is the main source for space(research) in Belgium. Although Science and Innovation are regional competences in Belgium, and the Flemish government carries out its own STI-policy, the federal government is still responsible for all matters concerning ESA and attends the ESA Ministerial Council meetings.

The recommendations in this advisory report are meant to convince the federal government to subscribe more to those optional programs that better reflect Flanders' technological expertise, thus enhancing the presence of Flanders in them. The recommendations (Part I) are based on a thorough analysis of the technological strengths of the Flemish space sector (industry, academia and research centers) (Part II).

MANAGEMENTSAMENVATTING

Met voorliggend advies wenst de Vlaamse Raad voor Wetenschap en Innovatie (VRWI) bij te dragen aan de voorbereiding van de verbintenissen die België zal opnemen tijdens de ESA-ministerraad in december 2016 voor wat de optionele ESA-programma's betreft. Tijdens deze ESA-ministerraad worden de krijtlijnen voor de komende jaren uitgezet en worden o.m. nieuwe optionele programma's opgestart. Op de optionele ESA-programma's kan elke lidstaat vrij intekenen op basis van aanwezige expertise.

Het is de federale overheid die bevoegd is voor het ruimtevaartonderzoek in het raam van internationale en supranationale instellingen en overeenkomsten of akten, en dus ook voor alle activiteiten met betrekking tot ESA.

Het VRWI-advies heeft de bedoeling de federale overheid te overtuigen meer in te zetten op die optionele ESA-programma's waarvoor Vlaanderen een sterk technologisch potentieel heeft, zodat de Vlaamse aanwezigheid daarin toeneemt. Dit kan ook de positie van België binnen de ESA-programma's ten goede komen. Daartoe heeft de Raad in dit advies een grondige analyse van de Vlaamse technologische sterktes en troeven uitgevoerd en aldus een aantal prioriteiten geformuleerd voor de optionele ESA-programma's.

- Vooral de zgn. technologieprogramma's als GSTP, ARTES en het nieuwe INCUBED zijn belangrijk voor Vlaanderen. Ze laten enerzijds toe om de bestaande topposities van Vlaamse actoren in stand te houden maar ook om naar een topniveau te evolueren waar actoren dit ambiëren. Hiervoor moeten er voldoende middelen beschikbaar zijn en is een toename van de Belgische intekening op deze technologieprogramma's ten opzichte van het verleden verantwoord.
- De VRWI vraagt ook extra middelen voor Vlaamse Prodex-projecten, gezien de duidelijke Vlaamse excellentie in een aantal technologiedomeinen, zoals de 'life sciences' en de 'physical sciences', inclusief in het kader van ISS. Dit zou ook toelaten de financiering van de volledige onderzoekstrajecten meer te ondersteunen.
- Daarnaast zijn er een aantal specifieke ESA-programma's waarvoor Vlaanderen sterke technologische spelers heeft die een rol kunnen opnemen. Dit is het geval voor de programma's Aardobservatie en Navigatie. De VRWI zou de Vlaamse expertise hierin graag weerspiegeld zien in een voldoende hoge Belgische intekening op deze twee programma's, waarbij prioritair voortgebouwd wordt op de reeds verworven posities in Vlaanderen.
- Voor Ariane en ISS – de twee grootste optionele ESA-programma's – zal Vlaanderen nooit een goede return kennen omdat de expertise zich hoofdzakelijk in Wallonië/Brussel bevindt. Om de return naar Vlaanderen voor deze twee programma's toch te verhogen, dient de federale

overheid bij het intekenen op Ariane en ISS meer aandacht te hebben voor de niche-mogelijkheden en expertise van de Vlaamse spelers.

De VRWI weet zich in zijn pleidooi gesterkt door de beslissing van de federale regering die het Belgisch mandaat vastlegde voor de ESA-Ministerraad te Luxemburg in 2014. In de notificatie daarvan wordt gesteld dat bij het uitwerken van een voorstel om bij te dragen aan de nieuwe ESA-programma's, voldoende kansen zouden worden geboden aan actoren uit het noorden van het land.

Tot slot vraagt de Raad dat de middelen die de federale overheid nu inzet voor ruimtevaart (jaarlijks ongeveer 200 miljoen euro voor ESA) op peil worden gehouden.

SITUERING

België heeft in het verleden een strategische keuze gemaakt voor ruimtevaartonderzoek en heeft als klein land een voortrekkersrol gespeeld bij Europese initiatieven in de ruimtevaartsector. België is in verhouding tot zijn bbp ook een belangrijke investeerder in ruimte(vaart)onderzoek.

In tegenstelling tot vele buurlanden heeft België ervoor geopteerd geen eigen operationeel ruimtevaartagentschap met eigen prioriteiten uit te bouwen. Evenmin heeft België een eigen ruimtevaartprogramma ter ondersteuning van activiteiten in het domein van ruimte(vaart)onderzoek opgezet. De activiteiten in België/Vlaanderen zijn grotendeels afgestemd op de grote internationale onderzoeksprogramma's die vnl. via overheidsparticipatie worden geregeld.

De European Space Agency (ESA), de belangrijkste coördinerende en uitvoerende organisatie in het Europees ruimte(vaart)onderzoek is momenteel dan ook voor Belgische/Vlaamse actoren de voornaamste speler. Jaarlijks draagt België ongeveer 200 miljoen euro bij aan ESA.

Het is de federale overheid die bevoegd is voor het ruimtevaartonderzoek in het raam van internationale en supranationale instellingen en overeenkomsten of akten, en dus ook voor alle activiteiten met betrekking tot ESA. Het is de federale programmatorische overheidsdienst (POD) Wetenschapsbeleid die instaat voor de opvolging en het beheer. Er is geen structureel overleg met de Gewesten en Gemeenschappen ter zake. Het enige overleg is van informele aard en gebeurt vooral met/tussen bedrijven en bedrijvenorganisaties zoals de Vlaamse ruimtevaartindustrie (VRI).

Het voorgaande betekent niet dat Vlaanderen geen eigen beleid en visie rond ruimtevaart kan uitbouwen. Mede in het vooruitzicht van het aangekondigde federale ruimtevaartagentschap, waarin de Gewesten inspraak zouden hebben, heeft de VRWI het initiatief genomen om een project rond ruimte(vaart)onderzoek op te zetten om een strategische visie voor Vlaanderen uit te tekenen.

Dit project is in twee luiken opgesplitst, conform een korte termijn- en een langere termijndoelstelling.

Doel van het eerste luik was om op korte termijn een gedegen onderbouw aan te leveren van de expertise en het potentieel in Vlaanderen met het oog op de Belgische intekening op de optionele ESA-programma's t.b.v. de ESA-ministerraad eind 2016. Voorliggend advies is het resultaat van deze oefening.

Doel van het tweede luik is om te komen tot een Vlaamse strategische visie voor ruimtevaartonderzoek, die niet alleen de groei van de bestaande Vlaamse ruimte(vaart)economie beoogt maar ook tot nieuwe opportuniteiten leidt die de Vlaamse economie en maatschappij in het geheel ten goede komen. Deze strategische visie zal ook kunnen dienen ter ondersteuning van de Vlaamse 'delegatie' in het toekomstig ruimtevaartagentschap, maar ook voor andere actoren zoals de Europese Commissie en de initiatieven die zij nemen inzake ruimtevaart.

DEEL I: ADVIES

Met voorliggend advies wenst de Vlaamse Raad voor Wetenschap en Innovatie (VRWI) bij te dragen aan de voorbereiding van de verbintenissen die België zal opnemen op de komende ESA-ministerraad van december 2016 voor wat de optionele programma's betreft. Het VRWI-advies heeft de bedoeling de federale overheid te overtuigen meer in te zetten op die optionele ESA-programma's waarvoor Vlaanderen een sterk technologisch potentieel heeft, zodat de Vlaamse aanwezigheid daarin toeneemt. Dit kan ook de positie van België binnen ESA ten goede komen.

De VRWI schuift hiertoe een aantal prioriteiten naar voor. Deze prioriteiten zijn gebaseerd op een grondige analyse van de Vlaamse technologische sterktes en troeven (zie Deel II Analyse).

Vooral de zgn. technologieprogramma's zoals GSTP en ARTES zijn belangrijk voor Vlaanderen. GSTP beoogt generische technologieontwikkeling en ARTES ondersteunt technologische ontwikkelingen in de telecomsector. Beide programma's maken het mogelijk voor Vlaamse spelers om hun toppositie te behouden, dan wel naar een topniveau te evolueren indien ze dit ambiëren. Daarom moeten er voldoende middelen beschikbaar zijn en is een toename van de middelen in deze technologieprogramma's ten opzichte van het verleden verantwoord. De VRWI vraagt dan ook een verhoging van de intekening op GSTP en GSTP IOD (meer in het bijzonder AIM voor wat IOD betreft) en ARTES. De analyse toont aan dat Vlaanderen over ruim voldoende excellente capaciteit beschikt om dit in te vullen.

Naast deze bestaande technologieprogramma's zal er op de komende ministeriële raad een nieuw technologisch programma voorliggen, genaamd EW INCUBED. Dit programma moet ondersteuning bieden voor technologieontwikkelingen in Aardobservatie. Gezien het succes met de al bestaande technologieprogramma's en de technologische sterktes in Vlaanderen binnen INCUBED zou dit nieuw technologisch programma ook de nodige middelen moeten krijgen.

In datzelfde opzet bieden de 'Opportunity Programs' binnen Telecommunicatie, en daarbinnen dan vnl. Govsatcom, eveneens mogelijkheden voor een aantal Vlaamse spelers. Ook hiervoor vraagt de VRWI dat bij de intekening voldoende rekening gehouden wordt met de Vlaamse expertise terzake.

Prodex is een heel belangrijk programma voor de universiteiten. Het laat toe onderzoek in een voorbereidende fase vorm te geven vanuit de kennisinstellingen. De VRWI vraagt extra middelen voor Vlaamse Prodex-projecten, gezien de duidelijke Vlaamse excellentie in een aantal technologiedomeinen, zoals de 'life sciences' en de 'physical sciences', inclusief in het kader van ISS. Dit zou ook toelaten de financiering van de volledige onderzoekstrajecten meer te ondersteunen. Prodex focust momenteel sterk op instrumentontwikkeling, maar het noodzakelijke onderzoek dat hieraan voorafgaat, alsook de verwerking van gegevens uit de experimenten, kunnen nu slechts in beperkte mate worden gefinancierd.

Daarnaast zijn er een aantal specifieke ESA-programma's waarvoor Vlaanderen sterke technologische spelers heeft die een rol kunnen opnemen. Dit is het geval voor de programma's Navigatie en Aardobservatie. De VRWI zou de Vlaamse expertise hierin graag weerspiegeld zien in een voldoende hoge Belgische intekening op deze twee programma's, waarbij prioritair voortgebouwd wordt op de reeds verworven posities in Vlaanderen. Voor Aardobservatie betekent dit niet alleen de nieuwe initiatieven (Saocom CS en Altius) maar ook de bestaande (Proba V).

Omdat de expertise voor Ariane en ISS – de twee grootste ESA-programma's – zich hoofdzakelijk in Wallonië/Brussel bevindt, zullen deze voor Vlaanderen nooit een goede return kennen. Om de return naar Vlaanderen voor deze twee programma's toch te verhogen, dient de federale overheid bij het intekenen op Ariane en ISS meer aandacht te hebben voor de niche-mogelijkheden en expertise van de Vlaamse spelers (zowel bedrijven als kennisinstellingen).

De VRWI weet zich in zijn pleidooi gesterkt door de beslissing van de federale regering die het Belgisch mandaat vastlegde voor de ESA-Ministerraad te Luxemburg in 2014. In de notificatie daarvan wordt gesteld dat bij het uitwerken van een voorstel om bij te dragen aan de nieuwe ESA-programma's, voldoende kansen zouden worden geboden aan actoren uit het noorden van het land, o.m. door de deelname te verhogen aan programma's zoals GSTP, SMI, ARTES en Prodex en door erover te waken dat er in Vlaanderen specifieke competenties in het domein van lanceerraketten worden ontwikkeld.

Omdat de VRWI op dit moment nog niet over voldoende budgettaire informatie beschikt, kunnen deze aanbevelingen nog niet worden vertaald in concrete cijfers. Wel vraagt de VRWI alvast dat de federale overheid haar inspanningen op het vlak van ruimtevaart aanhoudt en de bijdrage aan ESA op peil houdt.

Gehandtekend	*Gehandtekend*
Danielle Raspoet	Dirk Boogmans
Algemeen Secretaris	Voorzitter

DEEL II: ANALYSE

1. ESA

1.1. Algemeen

De European Space Agency (ESA) werd per conventie in de jaren 1970 opgericht. Het is een internationale organisatie met vandaag 22 lidstaten, waaronder België. De missie van ESA bestaat erin om vorm te geven aan de ontwikkeling van de Europese ruimtecapaciteit en ervoor te zorgen dat de investeringen in de ruimte voordelen blijven opleveren voor de burgers van Europa en de wereld.

In de conventie werden twee 'organen' gedefinieerd om ESA te laten functioneren: de Raad en de Directeur-Generaal. De Raad, waarin elke lidstaat is vertegenwoordigd, is het hoogste beleidsorgaan van ESA. De Raad komt bijeen wanneer nodig, hetzij op ministerieel of afgevaardigd niveau (ambtelijk niveau). Benoemd door de Raad, vertegenwoordigt de Directeur-Generaal het Agentschap in al zijn handelingen.

1.2. Werking ESA

Om zijn doelstellingen te halen maakt ESA gebruik van twee types programma's: verplichte en optionele programma's. Elke ESA-lidstaat draagt in het kader van de conventie bij tot de verplichte programma's in functie van zijn relatief economisch gewicht (bbp-aandeel). Voor België is dit ongeveer 2,5%. Op de optionele programma's kan elke lidstaat vrij intekenen en aangeven voor welk percentage wordt bijgedragen. Van zodra 75% van het door ESA voorgestelde budget voor een programma bereikt is, kan dit uitgevoerd worden. Deze beslissingen worden door de ESA-Raad genomen en wel op ministerieel niveau. Bij een beperkt aantal optionele programma's wordt niet met percentages gewerkt, maar met vaste bedragen. Dit zijn tot nu toe de programma's die voor België/Vlaanderen de belangrijkste waren.

Het ESA-budget wordt aangewend voor het uitvoeren van ESA-opdrachten via contracten afgesloten met deelnemers uit de verschillende lidstaten. ESA voert hierbij een 'open markt'-politiek: de keuze van de uitvoerders gebeurt op competitieve basis met inachtname van bepaalde regels. De 'juste retour' is één van de belangrijke regels die ESA in het kader van zijn procedures hanteert. Eenvoudig gesteld moet voor elke euro bijdrage van een land een euro naar het land terugvloeien onder de vorm van contracten. Naast de financiële garantie voor lidstaten dat het principe van de 'juste retour' met zich meebrengt, is ook de 'inhoud' die naar de actoren terugvloeit van belang. In functie van elk specifiek optioneel programma is dat verschillend.

1.3. ESA-ministerraad

De bevoegde ministers van de ESA-lidstaten komen om de 2 à 3 jaar bijeen (ESA-Raad op ministerieel niveau - MC) om het beleid te bepalen dat moet gevolgd worden. Tijdens deze ministerraden worden besluiten genomen over de hoofdlijnen voor de komende jaren, het niveau van de aan het agentschap gegunde middelen en de programma's. De ESA-ministers komen tevens bijeen om nieuwe programma's (genoemd optionele programma's) te starten of bestaande programma's te beëindigen.

Volgens de Belgische bevoegdheidsverdeling is het aan de federale staatssecretaris voor Wetenschapsbeleid om ons land te vertegenwoordigen op de ESA-ministerraden en aldaar de Belgische voorstellen te verdedigen.

Op een meer regelmatige basis komen voorgedragen afgevaardigden van alle lidstaten samen in zgn. 'gewone' ESA-raden op ambtelijk niveau. Tijdens deze sessies beoordelen ze elk programma, geven ze de prioriteiten aan en bepalen ze de vooruitgang in uitvoering. Ze keuren de budgetten, het financieel reglement en het personeelsstatuut goed. Meer in het algemeen nemen ze alle nodige maatregelen voor de verwezenlijking van de doelstellingen van het Agentschap.

Op 1 en 2 december 2016 is de volgende ESA-ministerraad gepland. Op deze ministerraad zullen nieuwe optionele programma's ter goedkeuring voorliggen.

Voorliggend document werd opgesteld ter voorbereiding van deze ministerraad en heeft tot doel te duiden in welke (nieuwe) optionele programma's Vlaanderen effectief en het best kan bijdragen, zijn deelname significant kan verhogen en waar de prioriteiten voor Vlaanderen zouden moeten liggen.

1.4. ESA-voorstel optionele programma's ministerraad december 2016

Het voorstel van programma's dat ESA eind dit jaar op de ministerraad zal voorleggen, wordt in onderstaande Tabel 1 weergegeven. Omdat de VRWI met dit advies enkel suggesties kan doen voor de optionele programma's, zijn enkel deze opgenomen. Tussen haakjes is telkens het bedrag vermeld dat ESA hiervoor zou willen besteden.

De optionele programma's beslaan een 8-tal thema's; Earth Observation, Telecommunication, Navigation, Space Transportation (waaronder Ariane), Human Spaceflight and Robotic Exploration Programmes (waaronder ISS), Technology Programmes, Security Programmes en Scientific support (Prodex = PROgramme for the DEvelopment of scientific EXperiments).

Tabel 1: ESA-voorstel voor optionele programma's[1]

II. ESA OPTIONAL PROGRAMMES

- II.1. Earth Observation (1 742 mio euro)
  - EOEP-5
    - SAOCOM CS phase C/D
  - EW GMECV+ (CCI+)
  - EW INCUBED
  - MICROCARB
  - EW ALTIUS
- II.2. Telecom (1 420 mio euro)
  - Core Competitiveness Programme
    - Artes Future Preparations
    - Artes Competitiveness and Growth (C&G)
    - ARTES Advanced Technology (AT)
  - Public Private Partnerships (PPPs)
    - Electra
    - SAT-AIS
    - Neosat
    - Iris
    - ICE phase 2
    - New PPPs
  - New Integrated Applications and downstream growth (ex IAP)
  - Opportunity Programmes
    - GlobeNet
    - GOVSATCOM
    - Pioneer
- II.3. Navigation (100 mio euro)
  - Navigation Innovation and Support Programme (NAVISP)
- II.4. Space Transportation (2 000 mio euro)
  - Launchers Exploitation and Accompaniment Programme (LEAP)
    - Ariane Classical and MCO
    - Ariane Supplementary
    - Vega Classical and MCO
  - Space Rider / PRIDE

[1] Bron: BELSPO, infodag 3 oktober 2016

VEGA-E Preparation Activities
VERTA Small Missions Opportunities
Ariane-6/VEGA-C - sup VEGA-C
Launchers Technology and Demonstrators Programme

II.5. Human Spaceflight and Robotic Exploration Programmes (1 649 mio euro)
- European Exploration Envelope Programme (E3P)
  - ISS
  - ExoMars
  - Luna-Resource Lander
  - SciSpace
  - ExPeRT, Human Exploration beyond LEO, Commercial partnerships

II.6. Technology Programmes (611 mio euro)
- GSTP
  - Develop
  - Make
  - Fly (SMI)
- GSTP IOD
  - Asteroid Impact Mission (AIM)
  - e.Deorbit Maturation Phase

II.7. Security Programmes (187 mio euro)
- Space Situational Awareness Programme (SSA)
  - SWE
  - NEO
  - SST
  - L1/L5 Phase A/B

II.8. Scientific Support (300 mio euro)
  - PRODEX

Binnen deze oefening is het interessant om nog een bijkomend onderscheid te maken tussen enerzijds ESA-programma's die inspelen op bestaande technologieën/ontwikkelingen om bijv. nieuwe satellieten te bouwen, en anderzijds de zgn. ESA 'technologieprogramma's' die toelaten (nieuwe) technologieën (verder) te ontwikkelen. Dit zijn GSTP, ARTES (dat onder Telecommunicatie valt) en INCUBED (een nieuw technologieprogramma dat onder Aardobservatie valt).

Ook binnen het Prodex-programma, een belangrijk instrument om het lopend onderzoek aan de kennisinstellingen te versterken, kan nieuwe technologie worden ontwikkeld, of zijn de projecten voorlopers van technologieontwikkeling.

Recent werd er een 'new Integrated Applications and downstream growth Programme' (ex IAP) opgezet, eveneens onder Telecommunicatie. Het doel hier is niet nieuwe technologieën te ontwikkelen maar veeleer om twee applicaties/technologieën samen te brengen om nieuwe innovatieve diensten aan nieuwe gebruikersgemeenschappen aan te bieden.

Gezien Vlaanderen zijn deelname wil versterken, zijn deze programma's zeer belangrijk. Daarbij komt nog dat deze programma's een grotere flexibiliteit bieden om individueel in te tekenen zodat ze voor Vlaanderen veel mogelijkheden bieden. Ze zijn dan ook in het rood, respectievelijk oranje aangeduid in de tabellen 1-3.

Een tweede onderscheid dat we voor deze oefening maken, is tussen die programma's waar het zwaartepunt eerder bij de industrie ligt, en die waar het zwaartepunt eerder bij de kennisinstellingen ligt. De programma's waar het zwaartepunt eerder bij de kennisinstellingen ligt, zijn in blauw geschreven in de tabellen 1-3.

1.5. Toegankelijkheid ESA-programma's

De toegankelijkheid tot deze programma's varieert. Er moet een onderscheid gemaakt worden tussen:

1. De technologische programma's:
    - Binnen Prodex, het ESA-instrument bij uitstek om het lopend onderzoek aan de kennisinstellingen te versterken, kan nieuwe technologie worden ontwikkeld, of zijn de projecten voorlopers van technologieontwikkeling. Voor de toegang tot Prodex is de goedkeuring van het voorstel door BELSPO bepalend.
    - GSTP, ARTES en ook INCUBED bieden uitgebreide opportuniteiten om de uitmuntende technologische posities uit te bouwen en/of te versterken. Voor de toegang tot deze programma's is de goedkeuring van het voorstel door BELSPO bepalend. De verdere uitwerking wordt dan met ESA besproken en gebeurt meestal op basis van een directe onderhandeling tussen ESA en aanvrager.
    - Het 'new IAP' programma is bedoeld om nieuwe diensten te ontwikkelen voor nieuwe gebruikers, dit op basis van bestaande ruimtevaarttechnologieën/applicaties. Dit programma kan door de Vlaamse partners eenvoudig worden benaderd, mits te onderzoeken wat er op de markt aan nieuwe diensten kan worden aangeboden aan nieuwe doelgroepen. Net zoals bij bovenvermelde programma's is de toegang afhankelijk van de goedkeuring van BELSPO, maar bijkomend stelt zich hier de eis van een duurzaam businessplan dat aan ESA moet worden voorgelegd ter

goedkeuring. Om dit verder te ondersteunen stelt BELSPO een voltijdse 'application brooker' ter beschikking om opportuniteiten met Vlaamse partners te detecteren.

2. In de niet-technologische programma's waar bijv. nieuwe satellieten of 'launchers' worden ontwikkeld daarentegen, volstaat een uitmuntende technologische positie niet meer om toegang te verzekeren. Op zijn minst twee factoren spelen een belangrijke rol in het effectief capteren van een markt:
    - Zijn de opportuniteiten in elk programma open of zijn er al voortrajecten of andere elementen die maken dat de kans op slagen beperkt of onbestaande is?
    - Beantwoorden de technologische uitmuntende posities van Vlaanderen aan de komende marktvragen/RFP's of moeten zij bijkomend worden versterkt met aanvullende technologieën?

2. STRATEGISCHE ANALYSE RUIMTEVAARTEXPERTISE VLAANDEREN

2.1. Methodologie

De analyse van de VRWI had tot doel de in Vlaanderen aanwezige technologische expertise voor ruimte(vaart)(onderzoek) in kaart te brengen en hierin sterktes, niches, opportuniteiten te detecteren zodat die strategisch kunnen worden ingezet, onder meer in het kader van ESA.

Een eerste fase in de analyse was het in kaart brengen van de in Vlaanderen aanwezige technologische expertise op het vlak van ruimte(vaart)(onderzoek) en het identificeren van sterktes hierin. Hiertoe gebeurde in eerste instantie een inventarisatie van het technologische potentieel in Vlaanderen aan de hand van een gerichte bevraging van relevante actoren in het veld (purposive sampling). 26 actoren waren betrokken: 12 grote en middelgrote bedrijven, 3 kleine bedrijven, de 5 Vlaamse universiteiten, 4 van de 5 Strategische Onderzoekscentra (SOC's), alsook het Studiecentrum voor Kernenergie (SCK) en het Von Karman Instituut (VKI).

Het verzamelen van de gegevens gebeurde aan de hand van een bevragingssjabloon, dat gebaseerd is op de ESA-technology tree (in bijlage*), "which provides a classification system for all technical knowhow that is available in ESA. The Technology Tree has a three-level structure. The first level of decomposition introduces 26 Technology Domains (TDs). The TDs are then further subdivided into Technology Subdomains (TSs) and Technology Groups (TGs), as appropriate."*

De respondenten werden verzocht om die technologiegroepen uit de ESA-technology tree aan te kruisen waarin zij actief zijn en daarnaast ook hun 'capability' voor die activiteit aan te geven met een score van 1-5. Hierbij staat 1 voor 'beperkte expertise', 3 voor 'leider in Vlaanderen/België' en 5 voor 'internationale topexpertise'. Dit zowel voor de huidige situatie als voor de toekomst.

Om de sterktes te identificeren werden op de verzamelde gegevens vervolgens een aantal analyses uitgevoerd, die vooral kwalitatief van aard waren. Er werd nagegaan:

1. Voor welke technologie (sub)domeinen uit de ESA-technology tree de deelnemende actoren op dit moment een uitmuntende en internationale toppositie innemen. Hiertoe werden de gegevens gescreend op de 'score 5' voor de opgegeven 'capability'.
2. Voor welke technologie (sub)domeinen er 'grotere gehelen' bestaan waarin zowel een grotere kritische massa (groot aantal actoren) en hoge expertise (hoge score ≥3) aanwezig zijn. Deze 'grotere gehelen' worden daarom verder in de tekst met de term 'zwaartepunten' aangeduid.
3. Waar de bedrijven een strategische groei naar niveau 5 ambiëren.

In de tweede fase werd een matching uitgevoerd tussen de eerder geïdentificeerde Vlaamse sterktes en de optionele programma's die ESA zal voorstellen op de ministeriële conferentie van december 2016. Hiertoe werd voor elk van de 26 technologiedomeinen uit de ESA-technology tree waarbinnen sterktes werden geïdentificeerd, nagegaan in welk van de ESA-programma's deze aan bod kunnen komen/een rol kunnen spelen.

Omdat uiteindelijk niet alleen de technologische excellentie bepalend is om te slagen (zie punt 1.5), werd ten slotte in fase 3 de toegankelijkheid van de ESA-programma's en de mogelijke 'readiness/commitment' van de actoren in rekening gebracht. Bijkomend werd daarom voor elk van de programma's die op de ESA-ministerraad zullen besproken worden, nagegaan in welke mate de Vlaamse sterktes hiertoe effectief toegang bieden. De toegang werd als volgt gequoteerd:

- X: onbepaald, gezien programma later nog moet worden gedefinieerd;
- 0: geen toegang;
- 1: toegang, maar de kans van slagen is zeer beperkt;
- 2: concrete opportuniteit, maar mits zware competitie;
- 3: zeer grote kans tot binnenhalen van het project.

2.2. Resultaat 1: Huidige Vlaamse technologische sterktes

Het resultaat van fase 1 uit de analyse is de identificatie van 18 technologische sterktes voor Vlaanderen. Deze zijn uitsluitend gebaseerd op technologische uitmuntendheid. De grootte van de actoren/omzet/ … werd hier niet in rekening gebracht. Het uitgangspunt kan zowel een heel sterke (soms individuele) uitmuntende actor zijn, dan wel een biotoop (een groter geheel) van verschillende sterke spelers, de zgn. 'zwaartepunten' (zie 2.1).

Noteer ook dat de actoren die binnen eenzelfde groter geheel actief zijn, niet automatisch (exact) dezelfde activiteiten/onderzoek uitvoeren. Het kan ook gaan om complementaire activiteiten, waardoor eventuele samenwerking een extra versterking van deze 'cluster' van actoren kan betekenen. Dit vergt een diepgaander analyse en is voer voor het tweede luik van het ruimtevaartproject.

1. Een eerste Vlaamse sterkte situeert zich binnen technologiedomein 1 'Onboard data systems' en is gebaseerd op één van de geïdentificeerde zwaartepunten nl. 'Microelectronics for digital and analogue applications', waarin negen actoren met een hoge mate van excellentie actief zijn (5 bedrijven, 1 universiteit, 1 onderzoeksinstelling en 2 SOC's). Dit zwaartepunt wordt aangevuld met een uitmuntende bedrijfspositie op het vlak van 'Payload data processing' en 'Onboard data management'. Ook hierbinnen hebben universiteiten en SOC's stevige posities en kunnen mogelijks de bedrijfsposities mits samenwerking versterken.

2. Binnen technologiedomein 2 'Space system software', kunnen we twee verschillende Vlaamse sterktes onderscheiden, die elk voortbouwen op een zwaartepunt binnen dit technologiedomein. De eerste sterkte bouwt voort op het zwaartepunt rond 'Space segment software', waarin zeven partners met een hoge mate van excellentie actief zijn (3 bedrijven, 3 universiteiten en 1 SOC). Dit wordt versterkt door een sterke bedrijfspositie op het vlak van 'Advanced software technologies'.

3. Het tweede zwaartepunt binnen technologiedomein 2 'Space system software', is 'Earth observation payload data exploitation', met in totaal negen partners met een hoge mate van excellentie die hierin actief zijn (3 bedrijven, 3 universiteiten, 1 onderzoeksinstelling en 2 SOC's).

4. Binnen technologiedomein 3 'Spacecraft electrical power' zien we individuele bedrijfssterktes op het vlak van 'Power system architecture', 'Power generation technologies' en 'Power conditioning and distribution including regulation, control and distribution', aangevuld met een sterke SOC-positie.

5. Op het vlak van 'Space weather' binnen technologiedomein 4 'Spacecraft environments and effects' zien we een sterke positie van een universiteit.

6. Binnen technologiedomein 5 'Space System Control' zien we een individuele technologische bedrijfssterkte op het vlak van 'Control systems engineering'. Ook vertonen de universiteiten en een van de SOC's hierin een sterke positie.

7. Technologiedomein 6 'RF Systems, payloads & technologies' toont individuele bedrijfssterktes op het vlak van 'Telecommunication systems/subsystems', 'Radio navigation systems/subsystems' en RF technologies and equipment. Het onderzoek aan de kennisinstellingen (universiteiten en SOC's) toont hier ook een hoge mate van excellentie en zou die bedrijfssterktes kunnen aanvullen.

8. De volgende Vlaamse sterkte vinden we in technologiedomein 8 'System design & verification' dat voortbouwt op twee technologie subdomeinen 'Mission and system specification' en 'System analysis and design' die beiden als zwaartepunt werden geïdentificeerd, met respectievelijk 5 actoren (4 bedrijven en 1 universiteit) en 7 actoren (4 bedrijven, 2 universiteiten en 1 SOC) met hoge mate van excellentie actief. Bovendien wordt dit aangevuld met een uitmuntende bedrijfspositie voor het technologie subdomein 'Collaborative and concurrent engineering' en voor 'System verification and AIT'. Deze sterktes bevestigen de capaciteit in Vlaanderen om als 'prime' te kunnen optreden in bepaalde ontwikkelingen.

9. Technologiedomein 9 'Mission operation and ground data systems' toont een individuele sterke technologische bedrijfspositie op het vlak van 'Mission operations'. Ook een van de universiteiten kent hier een technologische sterkte.

10. We onderscheiden eveneens een individuele technologische bedrijfssterkte binnen technologiedomein 10 'Flight dynamics and GNSS' voor wat betreft 'GNSS based high precision positioning and guidance - algorithms and their implementation'.

11. Binnen technologiedomein 12 'Ground station systems and networks' situeren zich individuele excellente bedrijfsspelers op het vlak van 'Ground station system' en 'Ground communications networks'. Een van de universiteiten kent hier een technologische sterkte.

12. Ook binnen technologiedomein 13 'Automation, telepresence & robotics' zien we een aantal individuele bedrijfsspelers op het vlak van 'Automation & robotics systems' en 'Automation & robotics components and technologies'. Daarnaast zien we ook bij twee universiteiten een sterke positie terzake.

13. Een Vlaamse sterkte situeert zich ook binnen de 'Life & physical sciences' (technologiedomein 14) waar 'Instrumentation in support of life sciences' als een zwaartepunt wordt geïdentificeerd waarin acht partners met hoge mate van excellentie actief zijn (2 bedrijven, 5 universiteiten en 1 onderzoeksinstelling). Dit wordt aangevuld door uitmuntende posities in 'Applied life science technology' en 'Instrumentation in support of physical sciences. Dit domein toont een heel belangrijke vertegenwoordiging van kennisinstellingen en sterke banden met specifieke bedrijven.

14. Binnen technologiedomein 15 'Mechanisms' situeert zich een individuele bedrijfsspeler met technologische sterktes zowel op het vlak van 'Non-explosive release technologies' als 'Mechanism engineering'.

15. Voor de volgende Vlaamse sterkte nemen we twee technologiedomeinen 'Optics' (16) en 'Optoelectronics' (17) samen. Hierin behoort 'Optical system engineering' tot de zwaartepunten

(5 actoren waarvan 2 bedrijven en 3 universiteiten), dat wordt versterkt door de uitmuntende bedrijfsposities in 'Optical component technology and materials' en 'Optical equipment and instrument technology'. Het technologie subdomein 'Detector technologies' is het tweede zwaartepunt (7 actoren; 3 bedrijven, 2 universiteiten, 1 onderzoeksinstelling en 1 SOC). De kennisinstellingen hebben binnen deze 'sterkte' stevige posities en kunnen mogelijks de bedrijfsposities mits samenwerking versterken.

16. Binnen technologiedomein 20 'Structures' zien we individuele sterke bedrijfsspelers op het vlak van 'Structural design and verification methods and tools' en 'Launchers, reentry vehicles, planetary vehicles'. Dit wordt aangevuld met een sterke positie van universiteiten.

17. Binnen technologiedomein 22 'ECLS and ISRU' zien we technologische sterktes op het vlak van 'Environmental control life support (ECLS)', zowel bij een bedrijf, een universiteit als een onderzoeksinstelling.

18. Binnen technologiedomein 24 'Materials & processes' zien we onder meer op het vlak van 'Materials processes' (waaronder 3D printing) sterke Vlaamse spelers zowel bij de bedrijven als de kennisinstellingen.

De analyse identificeert ook de twee subdomeinen van 'EEE components & quality' uit de ESA-technologie tree als zwaartepunten. We interpreteren dit echter meer als een nodige positie ter ondersteuning van andere domeinen zoals 1 en 5. Ten slotte is er binnen technologiedomein 25 'Quality, dependability and safety' een individuele sterkte op het vlak van 'Product and quality assurance'. Ook dit zien we meer als ondersteuning.

2.3. Resultaat 2: Ambities van bedrijven om door te groeien naar technologische topposities

De resultaten van vraag 3 (zie 2.1) tonen ook aan dat de ambities om een aantal nieuwe topposities in te nemen er wel degelijk zijn. Acht bedrijven geven dit namelijk expliciet aan. Om zulke posities te kunnen concretiseren is uiteraard een strategie nodig en zijn er ook middelen nodig. De technologische programma's van ESA, cf. 1.4 zijn hiervoor een instrument bij uitstek.

2.4. Resultaat 3: Matching Vlaamse sterktes aan de komende optionele programma's

In Tabel 2 worden de technologiedomeinen uit de ESA-technology tree gematcht aan de toekomstige optionele ESA-programma's. De eerste kolom uit de tabel geeft de verschillende optionele programma's weer zoals die door ESA zullen worden voorgesteld op de komende ministerraad. De 'technologieprogramma's' zijn in het roze gemarkeerd. De kolommen genummerd van 1 tot 26 geven de verschillende technologiedomeinen uit de ESA-technology tree weer. Met de kruisjes wordt aangeduid in welk programma het bewuste technologiedomein aan bod komt. De technologiedomeinen waarin zich de Vlaamse 'zwaartepunten' situeren zijn in een diepere tint blauw weergegeven, de individuele sterktes in een lichtere tint blauw. De domeinen waarin Vlaanderen geen technologische sterkte heeft, zijn niet gemarkeerd.

Afgaand op de technologische sterktes lijken de mogelijkheden voor de Vlaamse actoren binnen de toekomstige optionele programma's van ESA aanzienlijk te zijn. Maar, zoals in punt 1.5 uiteengezet, moet er ook rekening gehouden worden met de toegankelijkheid tot de programma's.

2.5. Resultaat 4: Matching Vlaamse sterktes aan de komende optionele programma's, rekening houdend met toegankelijkheid

In Tabel 3 ten slotte wordt rekening gehouden met de toegankelijkheid van de Vlaamse posities. De kruisjes uit Tabel 2 zijn hierin vervangen door cijfers die de toegankelijkheid aangeven, zoals opgenomen in punt 2.1. Voor onze oefening zijn enkel de (zeer) grote kans tot binnenhalen van het project (3) en de concrete opportuniteiten mits zware competitie (2)+(3) belangrijk. Ze zijn in het rood gemarkeerd.

Tabel 2: Matching Vlaamse sterktes aan de komende optionele programma's

		TECHNOLOGY Domains	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
NAL PROGRAMMES																												
II.1. Earth Observation																												
	EOEP-5		X	X	X		X	X	X	X	X	X		X			X	X	X		X	X	X			X		
		SAOCOM CS phase C/D	X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
	EW GMECV+ (CCI+)			X																								
	EW INCUBED		X	X	X		X	X	X	X	X	X		X			X	X	X		X	X	X			X		
	MICROCARB		X	X	X		X			X	X	X		X			X					X	X			X		
	EW ALTIUS		X	X	X		X	X	X	X	X	X		X			X	X	X		X	X	X			X		
II.2. Telecom																												
	Core Competitiveness Programme																											
		Artes Future Preparations						X	X	X	X	X		X			X				X	X	X			X		
		Artes Competitiveness and Growth (C&G)	X	X	X			X	X	X	X	X		X			X	X	X		X	X	X			X		
		ARTES Advanced Technolgy (AT)	X	X	X			X	X	X	X	X		X			X	X	X		X	X	X			X		
	Public Private Partnerships (PPPs)							X	X																			
		Electra	X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
		Neosat	X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
		Iris		X	X		X	X	X	X	X	X		X			X				X	X	X			X		
		ICE phase 2		X	X			X	X	X	X	X		X			X				X	X	X			X		
		New PPPs		X	X			X	X	X	X	X		X			X				X	X	X			X		
	New Integrated Applications and downstream growth (ex IAP)																											
	Opportunity Programmes																											
		GlobeNet	X	X	X		X	X	X	X	X	X		X			X	X	X		X	X	X			X		
		GOVSATCOM	X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
		Pioneer	X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
II.3. Navigatie - Navigation																												
	Navigation Innovation and Support Programme (NAVISP)		X	X	X		X	X	X	X	X	X		X			X				X	X	X			X		
II.4. Space Transportation																												
	Launchers Exploitation and Accompaniment Programme (LEAP)			X						X	X	X		X			X				X	X	X			X		
		Ariane Classical and MCO		X						X	X	X		X			X				X	X	X			X		
		Ariane Supplementary		X						X	X	X		X			X				X	X	X			X		
		Vega Classical and MCO		X						X	X	X		X			X				X	X	X			X		
	Space Rider / PRIDE			X	X		X			X	X	X		X			X			X	X	X	X			X		
	VEGA-E Preparation Activities			X						X	X	X		X			X			X	X	X	X			X		
	VERTA Small Missions Opportunities																											
	Ariane-6/VEGA-C - sup VEGA-C			X						X	X	X		X			X			X	X	X	X			X		
	Launchers Technology and Demonstrators Programme			X	X					X	X	X		X			X			X	X	X	X			X		
II.5. Human Spaceflight and Robotic Exploration Programmes																												
	European Exploration Envelope Programme (E3P)																											
		ISS		X	X			X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X		
		ExoMars	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X			X		
		Luna-Resource Lander	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X		X	X	X			X		
		SciSpace														X								X				
		ExPeRT, Human Exploration beyond LEO, Commercial partnerships		X	X										X	X	X	X	X	X				X				
II.6. Technology Programmes																												
	GSTP																											
		Develop	X	X	X	X	X	X	X				X		X	X	X	X	X	X				X	X		X	
		Make	X	X	X	X	X	X	X				X		X	X	X	X	X	X				X	X		X	
		Fly (SMI)								X	X	X		X							X	X	X			X		
	GSTP IOD																											
		Asteroid Impact Mission (AIM)	X	X	X		X	X	X	X	X	X		X			X	X	X		X	X	X			X		
		e.Deorbit Maturation Phase	X	X	X		X	X	X	X	X	X		X	X		X	X	X	X	X	X	X			X		
II.7. Security Programmes																												
	Space Situational Awareness Programme (SSA)																											
		SWE		X		X																						
		NEO		X				X	X				X		X			X	X									
		SST		X				X	X				X					X	X	X								
		L1/L5 Phase A/B			X					X	X	X		X							X	X	X			X		
II.8. Scientific Support																												
	PRODEX			XE		XC					XB					X								XA				

Tabel 3: Matching Vlaamse sterktes aan de komende optionele programma's, rekening houdend met de toegankelijkheid

TECHNOLOGY Domains	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
II. ESA OPTIONAL PROGRAMMES																										
II.1. Earth Observation																										
EOEP-5	2	2	3		3	2		1		1		1			1	2	2			1	0			1		
SAOCOM CS phase C/D	2	3	3		3	3		3		2		1			2					1	0			1		
EW GMECV+ (CCI+)		1																								
EW INCUBED	3	3	3		3	3		3		3		3			3	3	3			3	3			3		
MICROCARB	0	1	1		0			1		1		1			0					0	1			0		
EW ALTIUS	3	3	3		3	3		3		2		1			3	3	3			1	0			1		
II.2. Telecom																										
Core Competitiveness Programme																										
Artes Future Preparations						1		1		1		1			1					1	1			1		
Artes Competitiveness and Growth (C&G)	3	3	3			3		3		3		3			3	3	3			3	3			3		
ARTES Advanced Technolgy (AT)	2	2	2			2		2		2		2			2	2	2			2	2			2		
Public Private Partnerships (PPPs)																										
Electra	0	0	0		0	1		0		1		2			0					0	0			1		
Neosat	0	0	0		0	0		2		1		0			0					0	0			0		
Iris		0	0		0	1		0		1		0			0					0	0			0		
ICE phase 2		0	0			0		2		1		2			0					0	0			0		
New PPPs		X	X			X		X		X		X			X					X	X			X		
New Integrated Applications and downstream growth (ex IAP)																										
Opportunity Programmes																										
GlobeNet	0	0	0		0	0		2		0		2			0	0	0			0	0			0		
GOVSATCOM	0	0	0		0	2		2		1		2			0					0	0			0		
Pioneer	2	2	2		2	0		2		1		0			0					0	0			0		
II.3. Navigatie - Navigation																										
Navigation Innovation and Support Programme (NAVISP)	1	1	1		1	3		1		3		3			1					1	0			1		
II.4. Space Transportation																										
Launchers Exploitation and Accompaniment Programme (LEAP)		0						0		0		0			1					1	1			1		
Ariane Classical and MCO		0						0		0		0			1					1	1			1		
Ariane Supplementary		2						0		2		2			1					1	1			1		
Vega Classical and MCO		0						0		0		0			1					1	1			1		
Space Rider / PRIDE		2	2		2			3		0		0			2			2		2	1			1		
VEGA-E Preparation Activities		0						0		0		0			1			2		1	1			1		
VERTA Small Missions Opportunities		0																								
Ariane-6/VEGA-C - sup VEGA-C		0						0		0		0			1			2		1	1			1		
Launchers Technology and Demonstrators Programme		0	1					0		0		0			1			2		1	1			1		
II.5. Human Spaceflight and Robotic Exploration Programmes																										
European Exploration Envelope Programme (E3P)																										
ISS		2	0			1		0		0		0	0	2	1	1	1	1		0	0	1		0		
ExoMars	1	1	0		1	3		0		0		0	0	0	0	0	0	0		0	0			0		
Luna-Resource Lander	2	1	1		2	2		1		1		0	2	1	1	1	1			1	1			1		
SciSpace														3								3				
ExPeRT, Human Exploration beyond LEO, Commercial partnerships		1	0										1	1	1	1	1	1				1				
II.6. Technology Programmes																										
GSTP																										
Develop	3	3	3		3	3							3	3	3	3	3	3				3	3	3	1	
Make	3	3	3		3	3							3	3	3	3	3	3				3	3	3	1	
Fly (SMI)								3		3		0								2	0			1		
GSTP IOD																										
Asteroid Impact Mission (AIM)	3	3	3		3	3		3		3		0			2	1	1			2	0			0		
e.Deorbit Maturation Phase	2	2	2		3	2		3		2		0	2		1	1	1	2		2	0			1		
II.7. Security Programmes																										
Space Situational Awareness Programme (SSA)																										
SWE		2				1																				
NEO		2				1							1			1	1									
SST		2				1										1	1	2								
L1/L5 Phase A/B			2					3		2		0								1	0			0		
II.8. Scientific Support																										
PRODEX	3	3												3		3	2					3				

3. CONCLUSIES

We stellen ten eerste vast dat Vlaanderen een aanzienlijk aantal internationaal uitmuntende topposities heeft, zowel qua individuele actoren als in grotere gehelen waarin meerdere diverse actoren een hoge mate van technologische excellentie hebben bereikt. Deze technologische sterktes worden in punt 2.2 opgelijst. Naast de huidige sterktes, nemen we ook de ambitie waar van een aantal actoren om door te dringen tot de top.

Indien Vlaanderen zijn positie wil versterken is het zaak om:

- deze huidige topposities in stand te houden;
- de huidige topposities aan te vullen met bijkomende/nieuwe posities;
- te evalueren of deze topposities voldoende zijn om markten te capteren dan wel of die topposities moeten aangevuld/verbreed worden. De huidige technologische Vlaamse zwaartepunten (zie boven) geven mogelijks een indicatie van het potentieel in Vlaanderen om de krachten te bundelen/te versterken. Dit vergt een diepgaander analyse en is voer voor luik II van het VRWI-ruimtevaartproject.

Met deze technologisch sterke posities maakt Vlaanderen kansen binnen een aantal optionele ESA programma's:

- De (eerder algemene) technologieprogramma's springen er uit. Er bestaat geen twijfel over dat GSTP en ARTES (Telecom) belangrijk zijn voor Vlaanderen. De Opportunity Programmes binnen telecommunicatie, en daarbinnen dan vnl. Govsatcom (gouvernementele satellietcommunicatie, samen met de EC en het European Defence Agency (EDA), bieden eveneens opportuniteiten voor een aantal spelers. Het nieuw technologisch programma INCUBED, gericht op ontwikkelingen voor Aardobservatie, zou ook een belangrijke hefboom voor Vlaanderen kunnen betekenen.
- Prodex is een heel belangrijk instrument voor de universiteiten. Prodex laat toe onderzoek in een voorbereidende fase vorm te geven vanuit de kennisinstellingen. Gezien het belang van dit instrument, en de duidelijke Vlaamse excellentie in een aantal technologiedomeinen, zowel in de 'life sciences' als de 'physical sciences', inclusief in het kader van ISS, moet hier voldoende aandacht naar gaan.
- Tenslotte zijn er twee specifieke programma's nl. Aardobservatie en Navigatie waar Vlaanderen sterk kan in meespelen.

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Reason for change	Issue	Revision	Date
Initial issue	1	0	March 2003
Re-numbering of TD15	1	1	June 2003
Second issue: Full document update	2	0	November 2006
Further update of TDs 9-10-11-12 and reduction to two levels	2	1	April 2007
Review of 2.1 vs 1.1 correspondence matrix	2	1.1	March 2008
No change to content; layout changed to bring the document into the ESA STM series	2	1.2	September 2008
Third issue: Full document update Updated to 2nd edition of STM-277	3	0	October 2013

1 Introduction

1.1 Objective of this Document

The objective of this document is to present the ESA Technology Tree, which provides a classification system for all technical knowhow that is available in ESA.

The Tree was initially defined in the frame of the ESTER (European Space Technology Requirements database) consolidation activities performed in April/May 2002. The present issue (issue 3.0) is the result of the 2012 update carried out by TEC-T with the help of TECNET, and with the help of all the Technology Domain Responsibles (TDRs).

The Technology Tree presented in this document is a living tool and therefore will be subject to evolution as necessary.

1.2 Structure of the Technology Tree

The Technology Tree has a three-level structure. The first level of decomposition introduces 26 Technology Domains (TDs). The TDs are then further subdivided into Technology Subdomains (TSs) and Technology Groups (TGs), as appropriate.

For many ESA processes, only the first two levels of the Tree are used, namely the TDs and the TSs. An abbreviated version of the table is therefore also provided.

1.3 Document Overview

The document is divided into three sections and two Appendices:

Section 1 (this section) describes the objectives of the document, an outline of the changes between issues 2.1 and 3.0, a number of useful definitions and a brief historical background.

Section 2 contains an abbreviated version of the Tree (only TDs and TSs included).

Section 3 contains the full tabular format version, with descriptions (all levels included).

Appendix A provides the latest updated list of the TDRs (ESA contact point list).

Appendix B provides a detailed description of the changes between issues 2.1 and 3.0 of the Technology Tree, including a connectivity matrix between version 2.1 and 3.0.

In addition, an Excel file is provided on attached CD in order to facilitate the use of the Tree.

1.4 Historical Background

ESTER was initially structured around 56 separate TGs (originally referred to as Product Groups). During the 2002 update, however, the list grew to include 207 separate items. The main reason behind this growth was that data providers had introduced new groups in order to define more accurately their area of work or expertise. The resulting cumulative list was not well structured, and, not surprisingly, included many duplications and overlaps, thus penalising its overall function. In order to improve the situation and provide a more structured classification of technology, the concept of the Technology Tree was established.

Issue 1.1 of the Technology Tree was released in 2003 as the result of a collaboration between the Directorate of Technical and Operational Support (D-TOS) and the Technology Harmonisation and Strategy Division (IMT-TH).

Since the first issue in 2003, the Technology Tree has been used both by ESA (e.g. for ESTER, Harmonisation, ESA Technology Strategy Long-Term Plan, technology programme workplans), and by the European industry.

1.5 2012 Update

Since the last issue of the Technology Tree, things have changed both technologically and organisationally, plus a number of comments were made by users on both the content and the navigability of the Tree.

In response to the above comments, the 2012 Technology Tree update has been carried out according to the following guidelines:

- Contact all ESA TDRs for suggestions on changes and improvements to the Technology Tree
- Analyse all received input and identify areas where there might be overlaps or where there might be potential for misunderstanding
- Analyse areas where no changes have been made, in order to catch issues that might have been missed in previous reviews

Issue 3.0 of the Technology Tree now contains:

- 26 TDs (26 in issue 2.1)
- 101 TSs (92 in issue 2.1)
- 320 TGs (274 in issue 2.1)

The total number of entries for issue 3.0 is therefore 447. By comparison, issue 2.1 contained 392 entries, and issue 1.1, 411 entries. An outline of the changes introduced in this latest revision follows:

- 47 entries have been added
- 44 entries have an updated title
- 110 entries have an updated description
- 7 entries have been moved within the Tree
- 3 entries have been deleted
- 9 entries have been split into more than one entry
- 6 entries have been merged

More details about the changes, and a connectivity matrix between versions 2.1 and 3.0, are provided in Appendix B.

1.6 Technology Tree Objectives

The objectives of the Technology Tree are as follows

- To provide a classification of all technological expertise currently available in ESA for space activities.
- To provide guidance for the identification in ESA of individuals responsible for specific technology areas.

1.7 Definitions

In the context of this document, the following definitions are applicable:

Technology	A technology is defined as the technical knowhow that is required for the design, manufacture and test of a space product, including all related processes.
Product	Space products are all items needed for space activities that can be procured in the market, including services.

1.8 Granularity Guidelines

Consistent with the definition of technology given above, the granularity of the description of TD, TS and TG goes from more general (TD) to more specific (TG), as follows:

- TD: A technology domain includes knowhow relevant to a technical area that can be identified as being standalone and can therefore be considered independently of other TDs.
- TS: A decomposition of a TD to provide a more accurate description of its content in terms of different but related technical areas.
- TG: A further decomposition of each TS to identify a technology that is relevant to a family of products but that is not the description of a product in itself.

An example of a technology category is 3-B-II. The structure and levels are illustrated in Fig. 1.

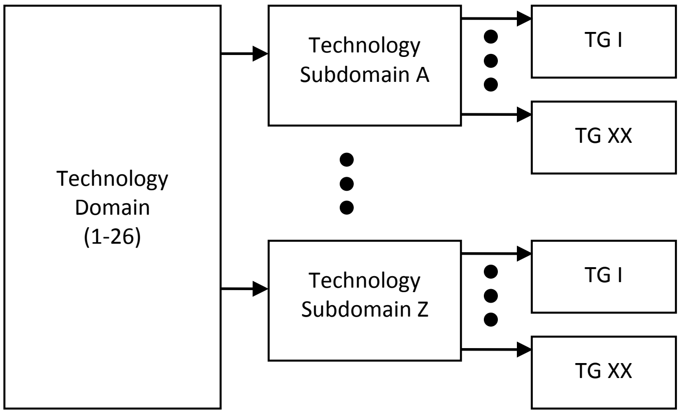

Figure 1: Structure of the Technology Tree

2 Technology Tree Issue 3.0 – Abbreviated Version

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
1	Onboard Data Systems	A	Payload data processing
		B	Onboard data management
		C	Microelectronics for digital and analogue applications
2	Space System Software	A	Advanced Software technologies
		B	Space segment software
		C	Ground segment software
		D	Ground data processing
		E	Earth observation payload data exploitation
3	Spacecraft Electrical Power	A	Power system architecture
		B	Power generation technologies
		C	Energy storage technologies
		D	Power conditioning and distribution including regulation, control and distribution
4	Spacecraft Environments and Effects	A	Space environment
		B	Environment effects
		C	Space weather
5	Space System Control	A	Control systems engineering
		B	Control systems innovative technologies
		C	Control techniques and tools
		D	AOCS/GNC sensors and actuators
6	RF Systems, Payloads and Technologies	A	Telecommunication systems/subsystems
		B	Radio navigation systems/subsystems
		C	TT&C and payload data modulator (PDM) systems/subsystems
		D	RF payloads
		E	RF technologies and equipment
7	Electromagnetic Technologies and Techniques	A	Antennas
		B	Wave Interaction and propagation
		C	EMC/RFC/ESD
8	System Design & Verification	A	Mission and system specification
		B	Collaborative and concurrent engineering
		C	System analysis and design
		D	System verification and AIT
9	Mission Operation and Ground Data systems	A	Advanced system concepts
		B	Mission operations
		C	Ground data systems (MCS)
10	Flight Dynamics and GNSS	A	Flight dynamics
		B	GNSS high-precision data processing
11	Space Debris	A	Ground- and space-based debris and meteoroid measurements
		B	Modelling and risk analysis
		C	Debris mitigation, debris environment remediation and protection
12	Ground Station System and Networks	A	Ground station system
		B	Ground communications networks
13	Automation, Telepresence & Robotics	A	Applications and concepts
		B	Automation & robotics systems
		C	Automation & robotics components and technologies

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
14	Life & Physical Sciences	A	Instrumentation in support of life sciences
		B	Instrumentation in support of physical sciences
		C	Applied life science technology
		D	Applied physical science technology
15	Mechanisms	A	Mechanism core technologies
		B	Non-explosive release technologies
		C	Exploration tool technologies
		D	Control electronics technologies
		E	MEMS technologies
		F	Tribology technologies
		G	Mechanism engineering
		H	Pyrotechnic technologies
16	Optics	A	Optical system engineering
		B	Optical component technology and materials
		C	Optical equipment and instrument technology
17	Optoelectronics	A	Laser technologies
		B	Detector technologies
		C	Photonics
18	Aerothermodynamics	A	Numerical methods
		B	Ground-based facilities
		C	Sensors and Measurement Techniques
		D	Flight databases
19	Propulsion	A	Chemical propulsion technologies
		B	Electric propulsion technologies
		C	Advanced propulsion
		D	Supporting Propulsion Technologies and Tools
20	Structures	A	Structural design and verification methods and tools
		B	High-stability and high-precision S/C structures
		C	Inflatable and deployable structures
		D	Hot structures
		E	Active/adaptive structures
		F	Damage tolerance and health monitoring
		G	Launchers, reentry vehicles, planetary vehicles
		H	Crew habitation, safe haven and EVA suits
		I	Meteoroid and debris shield design and analysis
		J	Advanced structural concepts and materials
21	Thermal	A	Heat transport technology
		B	Cryogenics and refrigeration
		C	Thermal protection
		D	Heat storage and rejection
		E	Thermal analysis tools
22	Environmental Control Life Support (ECLS) and *In Situ* Resource Utilisation (ISRU)	A	ECLS
		B	ISRU
23	EEE (electric, electromechanical & electronic) Components and quality	A	Methods and processes for product assurance of EEE components, including radiation hardness assurance
		B	EEE component technologies

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
24	Materials and Processes	A	Novel materials and materials technology
		B	Materials processes
		C	Cleanliness and sterilisation
		D	Space environmental effects on materials and processes
		E	Modelling of materials behaviour and properties
		F	Non-destructive inspection (NDI)
		G	Materials and process obsolescence
		H	Materials for electronic assembly
25	Quality, Dependability and Safety	A	System Dependability and Safety
		B	Software quality
		C	Product and quality assurance
26	OTHERS		

3 Technology Tree Issue 3.0 – Full Version

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
1	**Onboard Data Systems** Addresses both spacecraft data management and payload data processing and covers the hardware and software required for data acquisition, data processing, storage for both payload and spacecraft data, onboard networking and the space-link network layer and above.	A	**Payload Data Processing** Covering specific digital signal and data processing technologies and techniques, as well as specific (high-speed, high-capacity-oriented) hardware (e.g. DSP, storage), software (signal/image processing, data compression/fusion…) and networking technologies (including protocols and standards).	I	**System Technologies for Payload Data Processing** Covers system aspects such as payload processing and storage architectures, algorithms, communication, etc., for Earth observation, science and manned-space applications.
				II	**Hardware Technologies for Payload Data Processing** Covers hardware technologies related to high-speed/high-performance equipment (e.g. DSP, mass memories, switches and communication links, digital video, data compression).
				III	**Software Technologies for Payload Data Processing** Covers software technologies related to high-speed/high-performance payload data processing systems.
		B	**Onboard Data Management** Covers avionics and command & control system specific aspects, such as data handling, system management and autonomy, as well as specific hardware (e.g. computers, storage, micro-controllers), software (e.g. basic support packages) and networking technologies and techniques, etc.	I	**System** Highly integrated systems, architecture, fault tolerance, onboard operation management and autonomy.
				II	**Onboard Computers** Covers onboard fault-tolerant dependable computers, their main components (microprocessors, I/O) and basic software.
				III	**Data Storage** Covers the development of data storage equipment (mass memories) and modules for spacecraft platforms.
				IV	**Onboard Networks and Control/Monitoring** Covers the development of the onboard data communication systems, including onboard command and control data networks for performing monitoring and control across the platform, and wireless systems.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
1	**Onboard Data Systems (contd.)**	C	**Microelectronics for Digital and Analogue Applications** Covering design methodologies and technology for space application specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs). Digital and analogue designs, including IP cores.	I	**Methodologies** Rad-hardening by design allowing usage of commercial technologies; System-on-chip design methodologies; Hardware-Software co-design; usage of reprogrammable FPGAs for space applications; high-performance and low power signal processing algorithms and processors; analogue IC design. ASIC and FPGA design (design kit and libraries) and test tools. *(Note 1-C-I-1: Issues related to basic mechanisms of radiation effects are covered in TD 23)* *(Note 1-C-I-2: The software side of software–hardware co-engineering is covered in 2-B-II)*
				II	**Digital and Analogue Devices and Technologies** Reusable IP cores, (ASIC) processors, detector readouts and sensor electronics front-ends, standard ASICs and ASSPs (Application Specific Standard Products), FPGAs.
2	**Space System Software** Addresses both space and ground segment. All basic techniques and technologies in the fields of software and Information Technology with respect to their application to space missions.	A	**Advanced Software Technologies** Advanced software development (requirements, design, verification, validation, maintenance and qualification) methods/tools. Advanced functions to be implemented in software. Both ground and space application included. Development of related standards.	I	**Advanced Software Development Methods and Tools** Methods and tools for the software development that are innovative in the commercial world and require analysis prior to adoption in the space domain. This includes for example the OMG (Object Management Group) technologies, new languages, etc.
				II	**Advanced software functions** New functions of the software systems that are anticipated to be needed but that need predevelopment or prototyping before actual space development. Includes autonomy, parallel computing, etc. *(Note 2-A-II-1: This includes also predevelopment for applications indicated in TD1-A-III)*
		B	**Space Segment Software** Onboard software requirements, design, verification, validation, maintenance and qualification methods/tools. Specific aspects related to the application of modern IT technologies. Includes flight software and related simulator technologies.	I	**Methods and Tools for Onboard Software Engineering Processes** All aspects of onboard software engineering, requirement engineering, automation of the life cycle, testing, model-based development, etc. In particular, it includes software emulators of onboard processors.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	**Space System Software (cont.)**	B	**Space Segment Software (cont.)**	II	**Innovative Software Management Process** Adaptive engineering, new planning approaches, cost estimation methods, distributed development. The focus is on the system aspects of software, the system–software co-engineering. Includes also software–hardware co-engineering. *(Note 2-B-II-1: The system side of system–software co-engineering, and the hardware side of software–hardware co-engineering, are covered in 8-A-I and 1-C-I respectively.)*
				III	**Software Architectures** Software architectures for space segment software. Includes e.g. concepts such as Arinc653. In particular, it includes also Plug and Play technologies.
		C	**Ground Segment Software** Mission control system software design, verification, validation and maintenance methods/tools. Application of modern IT technologies to spacecraft operations, including Object-Oriented Technologies.		
		D	**Ground Data Processing** Covers archiving systems and analytical processing of space data.	I	**Data Archiving Systems** Long-term data storage, large data volume technology…
				II	**Analytical Processing** Data mining, feature extraction…
		E	**Earth Observation Payload Data Exploitation** Technologies associated with development and operation of ground segment infrastructure and facilities (including user interfaces, mission analysis/planning, payload data acquisition, archiving, processing, dissemination, quality control), provision of related data and information to user communities, support to data utilisation, applications and services, creation of higher-level information products and the creation and provision of information-based services.	I	**Data and Information Processing and Exploitation** Covers aspects related to data and information acquisition, archiving, processing, dissemination, and quality control, and to mission planning. Also covers exploitation of federated and collaborative payload data ground segment services and data dissemination.
				II	**Applications and Services** Covers aspects related to applications (e.g. algorithms, models, related environments, etc.), higher-level processing, information mining, information-based services, service support, outreach.
				III	**Information Systems and User Interfaces** Covers aspects related to systems for accessing data and information and user interface tools and methods.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	**Space System Software (cont.)**	E	**Earth Observation Payload Data Exploitation (cont.)**	IV	**Core Infrastructure and Architectures** Covers aspects at ground segment level, like architectures, common infrastructure, support to management and operations, automation,…
3	**Spacecraft Electrical Power** Addresses the techniques and technologies related to power system architecture, to power generation, distribution and conditioning and to energy storage.	A	**Power System Architecture** Including power system topologies, sizing, modelling and simulation tools and techniques.		
		B	**Power Generation Technologies**	I	**Photovoltaic Generator Technology** Including solar cells (crystalline and thin films), photovoltaic assembly and solar array technologies.
				II	**Fuel Cell Technologies**
				III	**Nuclear and Thermo-Electric Power Generator Technologies**
		C	**Energy Storage Technologies**	I	**Electro-Chemical Technologies for Energy Storage**
				II	**Mechanical Technology for Energy Storage** *(Note 3-C-II-1: Detailed mechanisms aspects are covered in TD15)*
		D	**Power Conditioning and Distribution** Including regulation, control and distribution.	I	**Power Conditioning** PCUs, DC/DC converters, SAR, BDRs, BCRs etc.
				II	**Specific Power Supplies** PPUs, high-voltage EPCs, wheel electronics, etc.
				III	**Power Distribution** Solid-state switches, PDUs.
4	**Spacecraft Environments and Effects** Space environmental effects are limiting on all space missions and need to be assessed during all mission phases. Assessment requires the creation of environment models and the knowledge of effects, which is obtained by inflight measurement and testing.	A	**Space Environment** Methods and models, and inflight monitoring of space environments (including radiation, plasmas, micrometeoroids and micro-debris, atmosphere and contamination).	I	**Numerical modelling of environments** Establishment of numerical models that represent space environments and their variables, as required by mission development and operation. Associated data analysis, and systems delivering model output for efficient use in development and operations.
				II	**Inflight Monitoring** Technologies to gather data on the space environment. Includes radiation detection (fluxes and derived quantities for all radiation components), plasmas, direct microparticle detection.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
4	**Spacecraft Environments and Effects (cont.)**	B	**Environment Effects** Covers effects due to space environment (radiation damage and interference, spacecraft charging, microparticle impact risk, …) development of computational tools and related experimental investigations.	I	**Effects Analysis Tools** Development of tools for each environmental domain and resources for coordinated assessment. Tools for use in development and operations for quantifying environmental effects in terms of engineering parameters, and for use in product assurance and testing.
				II	**Ground and Space Effects Investigations** Providing data for the development and validation of the analysis tools and including establishment and/or exploitation of on-ground and in-space investigations of the environments and the effects on technologies. Includes radiation effects, charging and ESD monitoring, direct and indirect impact detection, analysis of returned material, etc.
		C	**Space Weather** Covers technology developments that contribute to the establishment of capabilities for predicting or evaluating hazardous environmental conditions in space, in the ionosphere or on the ground due to space weather, through use of observation technologies coupled with modelling and IT technologies. The observations and modelling relate to phenomena on the Sun, in interplanetary space and coupling with the near-Earth environment.	I	**Modelling Development and IT Infrastructure** Development of numerical models in the various space weather domains (solar, heliospheric, magnetospheric, ionospheric). Also covers IT infrastructure: development of an integrated but distributed system that includes realtime and archived data, coupled modelling and user-oriented informatics tools.
				II	**Space Weather Monitoring Technology** *In situ* and remote measurement of space weather features for use in forecasting and nowcasting, including solar, heliospheric, magnetospheric and ionospheric domains.
5	**Space System Control** Covers the design and implementation of control systems for space applications. Includes AOCS for satellites; GNC for space vehicles and launchers; pointing acquisition and tracking systems for antennas, laser terminals, and line-of-sight stabilisation equipment.	A	**Control Systems Engineering** Covers system aspects and AOCS/GNC functional chain engineering.	I	**AOCS/GNC Architecture** Includes concept and mode definition, and selection and accommodation of sensors and actuators.
				II	**Autonomy and FDIR** Covers control-related aspects and implementation (with TD2 and TD9-B).
				III	**Pointing Error Engineering** Covers budget methodology and tools.
				IV	**Control Requirements Engineering** Includes software algorithm specification (with TD2) and sensor and actuator specification.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
5	**Space System Control (cont.)**	A	**Control Systems Engineering (cont.)**	V	**Control Design and Verification** Includes detailed analysis and performance verification on functional engineering simulators and avionic test benches.
		B	**Control Systems Innovative Technologies** Covers enabling technology developments dedicated to specific missions and generic applications.	I	**GNC Technologies for Entry, Descent and Landing** Covers GNC technology developments for aerobraking, precision landing, hazard avoidance, realtime guidance and navigation, specialised simulation tools and test beds.
				II	**GNC Technologies for Cruise, Rendezvous and Docking or Capture** Covers GNC technology developments for exploration as well as active debris removal.
				III	**High Accuracy Pointing Technologies** Covers technology developments in AOCS and pointing acquisition and tracking systems.
				IV	**Competitive AOCS Technologies** For commercial and generic applications, tackling cost reduction at all levels (design and verification effort, building-block approach, hybridisation of sensors, …).
		C	**Control Techniques and Tools** Covers generic and advanced techniques dedicated to design analysis and verification.	I	**Modelling Techniques** Covers mathematical modelling and software model development for: satellite dynamics and environment, sensors and actuators, and software components.
				II	**Advanced Control, Estimation & Optimisation** Covers the development of efficient techniques and tools for design analysis and verification.
				III	**Multidisciplinary Optimisation** Includes the development of mathematical solvers and tools for concurrent optimisation of GNC-related aspects of the space vehicle and trajectory.
		D	**AOCS/GNC Sensors and Actuators** Covers the specification and development of generic and custom products based on mission and market needs.	I	**AOCS/GNC Optical Sensors** Startrackers, Sun and Earth sensors, optical navigation sensors. Includes detectors (with TD17-B), optics (with TD16), microelectronics (with TD1-C), electronics, image processing, software algorithms.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
5	**Space System Control (cont.)**	D	**AOCS/GNC Sensors and Actuators (cont.)**	II	**AOCS/GNC Inertial and Magnetic Sensors** Gyros, acceleros, IMUs, magnetometers. Includes MEMS, HRG, FOG technologies, control loops and hybridisation, microelectronics (with TD1-C), electronics.
				III	**AOCS/GNC Inertial and Magnetic Actuators** Reaction wheels, CMGs, magnetic torquers). Includes control loops, mechanisms & tribology (with TD15-F/G), power electronics (with TD3-D), microelectronics (with TD1-C).
6	**RF Systems, Payloads and Technologies** Covers all technologies and techniques operating in the RF domain related to satellite systems and networks, spacecraft payloads, instruments and specific ground equipment (see note below), for telecommunication, TT&C, navigation, Earth observation and space science, including security aspects. *(Note 6-1: Technologies for control centres, TT&C and Earth Observation Payload Data Transmission Ground Stations and Ground Station Networks are covered in TD12)*	A	**Telecommunication Systems/Subsystems** Covers telecommunication techniques and algorithms (coding, modulation, access, synchronisation, networking, security etc.), system tools and telecom equipment.	I	**Telecom System Engineering Tools** Covering all aspects related to satellite telecom system and subsystem analysis, design tools and methodologies.
				II	**Telecom Signal Processing** Covering all signal processing techniques and algorithms related to coding/decoding, modulation/demodulation, access, synchronisation, medium access control.
				III	**Networking Techniques** Covering telecom satellite networking aspects related to radio resource management, network management and control aspects, traffic modelling, etc.
				IV	**Telecom Equipment** Covering all baseband telecom equipment (e.g. modulators, demodulators, front-ends). Used for fixed, mobile and broadcast satellite or hybrid satellite/terrestrial telecom systems, also including user terminals.
				V	**Telecom Security Techniques and Technologies** Covering the techniques and technologies to secure end-to-end telecom systems.
		B	**Radio Navigation Systems/Subsystems** Covers radio navigation techniques and technologies, elements and subsystems capable of generating, receiving, exploiting and analysing the signals from current and upcoming radio navigation systems (GPS, Glonass, EGNOS, Galileo), including system tools and navigation equipment.	I	**Navigation System Tools** Covering all aspects related to ground and space navigation systems, subsystems, Signal in Space, simulators, analysis tools and methodologies.
				II	**Ground Receivers** Covering all technologies related to RF and baseband aspects, positioning and integrity algorithms, integration with other sensors, local augmentation, and integration with telecommunication systems and services.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	**RF Systems, Payloads and Technologies (cont.)**	B	**Radio Navigation Systems/Subsystems (cont.)**	III	**Onboard Receivers** Covering all aspects related to navigation space receivers or reference receivers, algorithms and technologies.
				IV	**Formation-flying RF metrology** Covering all aspects related to high accuracy RF metrology required for formation-flying applications, including algorithm technology and tools.
		C	**TT&C and Payload Data Modulator (PDM) Systems/Subsystems** Covers both spacecraft TT&C/PDM techniques and technologies, space-link communications (RF, hybrid RF/optical systems, signal coding/modulation, ranging techniques, radio science experiments) and proximity links.	I	**TT&C System Tools** Covering all aspects related to TT&C systems (coding, modulation, multiplexing, link analysis, interference) and subsystem analysis tools and methodologies.
				II	**Deep-Space Transponders** Covering all aspects related to the design and development of deep-space TT&C transponders.
				III	**Near-Earth Transponders** Covering all aspects related to the design and development of near-Earth TT&C transponders.
				IV	**Proximity Link** Covering all aspects related to the design and development of units for proximity link applications.
				V	**High-speed Downlink PDM** Covering all aspects related to (coded) modems for high-speed payload downlink (e.g. for EO, DRS applications).
		D	**RF Payloads** Covers telecommunication payloads (transparent and regenerative), remote sensing instruments, and navigation payloads exploiting analogue, digital and optical technologies.	I	**Payload Tools** Advanced simulation tools and analysis paradigms for complex payloads for Telecom/EO/Navigation.
				II	**Telecommunication Payloads** Covering telecommunication payloads and architectures encompassing RF, digital and optical technologies.
				III	**EO Instruments** Covering EO instruments both passive (e.g. radiometers, GNSS-R) and active (e.g. SAR, altimeters, RF sounding).
				IV	**Navigation Payloads** Covering navigation payload systems and subsystems.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	**RF Systems, Payloads and Technologies (cont.)**	E	**RF Technologies and Equipment** Covers RF equipment, subsystems and building blocks, active and passive components, and related design and characterisation tools in the whole RF domain. *(Note 6-E-1: All quasi-optic and free-space aspects are covered by TD7 and TD12)* *(Note 6-E-2: All quality aspects are covered by TD23 and TD25)* *(Note 6-E-3: All ground station RF technologies for TT&C and payload data are covered by TD12)*	I	**RF Modelling and Design Tools** Covering design and analysis tools for RF equipment and components.
				II	**RF Equipment** Covering RF equipment and subsystems (e.g. SSPAs, LNAs, frequency converters and multipliers, local oscillators and synthesisers, multiplexers).
				III	**RF Devices** Covering the design, specification, development and characterisation of active devices (e.g. diodes, transistors, mixers, multipliers, integrated circuits) and passive devices (e.g. filters, resonators, MEMS devices, cables and connectors), including packaging and interconnection.
				IV	**Vacuum Electronics** Covering technologies and techniques related to high-power RF amplification using vacuum electronic devices (e.g. TWT).
				V	**Time and Frequency** Covering the techniques and technologies for the generation of reference signals (oscillators and clocks of all types, e.g. quartz, VCOs/NCOs, Rb, Cs, H-maser) and their means for comparison and dissemination as required for telecom, navigation and science applications. *(Note 6-E-V-1: Optical atomic clocks are covered in 17-C-IV)*
				VI	**RF Measurement, Characterisation and Calibration Techniques** Covering RF equipment and components, including for high-power, corona and multipactor testing.
7	**Electromagnetic Technologies and Techniques** Covers antennas and related technologies, wave interaction and propagation, and electromagnetic compatibility.	A	**Antennas** Covering antenna systems and architectures, design tools, technologies and measurement techniques for various applications for space systems and ground users, up to THz frequencies, such as communications, navigation or sensing, spacecraft pointing, TT&C, etc. *(Note 7-A-1: Ground TT&C antennas are covered in 12-A-II)*	I	**Antenna Design Tools** Covering modelling, synthesis and optimisation techniques and tool development for new types of antennas and their feed networks, arrays, reflector and small antennas, both isolated and in the spacecraft environment.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
7	**Electromagnetic Technologies and Techniques (cont.)**	**A**	**Antennas (cont.)**	II	**Reflector and Lens Antennas** Covering single and multiple beam reflector antenna architectures, reflector design, multiple reflectors, reconfigurable reflector antennas, shaped, unfurlable and foldable reflectors, frequency- and polarisation-selective surfaces, active and passive lenses, feed elements and feed arrays with their feed networks, reflect-arrays.
				III	**Array Antennas and Standalone Radiators** Covering planar and conformal arrays, multi-frequency arrays, dual-polarisation arrays, active, semi-active and passive arrays. Small arrays and standalone radiators for medium and low gain applications for spacecraft and for user terminals. Array feed networks. Electronic scanning arrays. Fixed and steerable beam arrays for fixed and mobile user terminals. Satellite TT&C standalone and multi-element antennas.
				IV	**Millimetre-Wave and Sub-Millimetre-Wave Antenna Front-Ends** Covering antennas, instruments, new architectures and technologies for THz passive and active remote sensing instruments such as radiometers, imagers, limb sounders. Also reflectors and quasi-optic assemblies, focal plane arrays and front-ends.
				V	**Measurement, Characterisation and Calibration Techniques for Radiative Payloads and Antennas** Covering new antenna and payload measurement techniques (e.g. for multi-beam payloads), validation of modelling software, techniques for measurement of antennas in the spacecraft environment, interactions between antennas, millimetre-wave and THz antennas. RF characterisation of reflective and transparent materials.
		B	**Wave Interaction and Propagation** Covering technologies and techniques related to propagation models and modelling techniques, interference modelling and experimentation, wave interaction modelling, and associated retrieval algorithms and models. Applications are telecommunications, navigation, remote sensing (both for Earth and planets), TT&C and payload data transfer.	I	**Wave Interaction** Covering modelling of wave interactions for passive and active microwave and optical remote sensing of atmosphere, surface and subsurface features of Earth and planets. Retrieval algorithms.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
7	**Electromagnetic Technologies and Techniques (cont.)**	**B**	**Wave Interaction and Propagation (cont.)**	II	**Wave Propagation** Covering propagation and interference models and their validation at microwave and optical frequencies through Earth and planetary atmosphere, stratosphere, ionosphere. Microwave propagation in urban and indoor environments. Link budgets in complex propagation environments.
		C	**EMC/RFC/ESD** Covering design, models, simulation, testing techniques and technologies in the fields of electromagnetic compatibility (EMC), radio frequency compatibility (RFC), electrostatic discharge (ESD), and magnetic cleanliness.	I	**EMC Modelling and Simulation** Covering development of specific EMC models and simulation tools for application to spacecraft.
				II	**EMC Test Techniques** Covering validation of new EMC designs and novel EMC and magnetostatic test methods for application to spacecraft.
8	**System Design & Verification** Covers technology, methods and tools to support system engineering processes (specification, design, and verification) of space systems during the complete mission lifecycle (phases 0 to F). Focuses on reducing the schedule and/or cost of development of the space system (i.e. space and ground segment) whilst controlling quality and risk (mission success) to the required level. It covers new paradigms (e.g. model-based systems engineering), approaches and techniques for the development of space systems, which are mostly common to several service domains.	A	**Mission and System Specification** Covering the early phases of a project development life cycle, focusing on requirement engineering, specification and architecture formulation.	I	**Specification Methods and Tools** Methods and tools to support the capture, modelling and validation of requirements, including definition and formalisation of system architectures.
				II	**Requirement Engineering** Methods and tools to support the system requirement engineering process, including requirement management and related database issues.
		B	**Collaborative and Concurrent Engineering** Covering aspects related to the process of concurrent engineering as well as the data underlying multidisciplinary collaboration.	I	**Concurrent Design** Includes methods and tools to provide an integrated environment for the concurrent design of a mission/system.
				II	**Data Exchange** Covering methods and standards to support the exchange of multidisciplinary data, focusing on the data aspects of collaborative engineering.
				III	**Collaborative Engineering** Covers methods and tools to support collaboration of remotely-located engineering teams and access to remote models/data. Includes aspects of interoperability and deployment of corresponding tools.
		C	**System Analysis and Design** Including system-to-subsystem interaction and interfaces, relationships between domain-level analyses and system-level analyses.	I	**Design and Simulation** Includes methods and tools to support the modelling and simulation-based design and verification at system level.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
8	**System Design & Verification (cont.)**	**C**	**System Analysis and Design (cont.)**	II	**Multidisciplinary Analysis** Includes methods and tools to support coordinated analyses for different technical disciplines.
		D	**System Verification and AIT** Covering methods, tools and infrastructure necessary to integrate and verify space systems.	I	**Advanced AIT Methods** Covering advanced methods, tools and standards to support the assembly, integration and testing plus verification of space systems across the life cycle.
				II	**Ground Support Equipment** Covering advanced tools and standards for supporting ground activities in all domains across the life cycle. *(Note 8-D-II-1: GSE for propulsion systems is included in 19-D-IV)*
9	**Mission Operation and Ground Data Systems** Addresses aspects related to the control and operations of space system elements (satellites, transfer vehicles, orbiters, landers, probes, rovers, etc.) and related ground segments, addressing the technologies associated with supporting systems and tools.	A	**Advanced System Concepts** Covering studies, technology investigations and prototyping related to the implementation and validation of innovative or advanced system and mission operation concepts.	-	-
		B	**Mission Operations** Covering aspects related to operation processes and mission control concepts, including automation, autonomy at various levels and distribution/decentralisation, operations support processes (such as operation training) and associated tools, dependability of operation systems and processes.	I	**Distributed and Decentralised Operations** Includes operations of single missions and families of missions, formation flying and constellations.
				II	**Automation, Autonomy and Mission Planning Concepts** Includes concepts for automation and mission planning of ground data systems and spacecraft operations.
				III	**Operation Support Processes** Covering aspects such as operation preparation, knowledge transfer from manufacturer to operations, training, dependability of operation systems and processes.
		C	**Ground Data Systems** Covering technologies and techniques related to mission control systems (MCS's), SIM and DC architectures, techniques and tools for operations planning and scheduling, commonalities of AIV and operations, decision support and process control, operations data archiving and access, human–computer interfaces (HCIs).	I	**Mission Control System, Automation, Mission Planning, Simulators and Station M&C and Data Centre Architecture and Technologies** Includes architectural concepts, definition of a general framework, a set of building blocks/libraries for any type of mission and state of the art technologies for Ground Segment CSOS (Complex System of Systems).
				II	**Preparation and Procedure Tools** Taking into account commonalities with EGSE requirements.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
9	**Mission Operation and Ground Data Systems (cont.)**	**C**	**Ground Data Systems (cont.)**	III	**Human–Computer Interfaces and Technologies** Includes frameworks, toolkits and other aiding tools that ease the definition of HCI, sharing a common look and feel and usability.
10	**Flight Dynamics and GNSS** Comprises the activities related to the analysis and definition of trajectory aspects of space projects, known as mission analysis. It includes all operational ground activities related to the measurement and control of spacecraft orbit and attitude. Furthermore it deals with the provision of precise navigation services to both ground and space-based users and also the provision of the geodetic reference frame.	A	**Flight Dynamics (FD)** Flight dynamics support addresses the trajectory and attitude aspects of space missions. This includes the pre-flight trajectory design (mission analysis). In flight, it includes the determination and control of trajectory and attitude of the spacecraft, monitoring of spacecraft AOCS and generation of orbit- and attitude-related command parameters. The FD domain of expertise comprises mathematics, dynamics, optimisation and environment modelling. FD support is mission critical and thus must be correct, robust, reliable and flexible.	I	**Mission Analysis and Trajectory Design** Covers pre-flight spacecraft mission design, trajectory optimisation and launch window calculations.
				II	**Advanced Flight Dynamics Operations** Covers high-precision navigation at minor bodies, interplanetary RVD and formation control, FD support to GNC systems including novel sensors and actuators; aerocapture and aerobraking; entry, descent and landing; high-precision formation-flying control; high-precision orbit control for Earth observation.
				III	**Advanced Flight Dynamics Processes and Tools** Covers automation of flight dynamics operations, advanced modules of FD application SW and advanced operational processes.
		B	**GNSS High-Precision Data Processing** Covers operation of GNSS sensor networks, GNSS-related data processing, techniques for precise orbit- and clock-determination concepts for MEOs and LEOs and satellite geodesy.	I	**Ground Tracking Networks** Covers the deployment, operation and data collection for GNSS sensor stations, network management, data handling services.
				II	**GNSS and Geodetic Data Processing** Models, algorithms, data monitoring, data quality assessment and delivery of services and products.
				III	**MEO and LEO Precise Orbit Determination Algorithms** Orbit dynamics and related models, analytical and numerical algorithms, for realtime (ground) and non-realtime (onboard/ground) data processing, performance analysis.
				IV	**Geodetic Reference Frames** Satellite geodesy, standards, processing of different observations.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
11	**Space Debris** Covering all aspects related to knowledge of the meteoroid and debris environment including space surveillance, databases, assessing debris risk levels for current and future missions, reentry of space objects, hyper velocity impacts and protection, and mitigation measures.	A	**Ground- and Space-based Debris and Meteoroid Measurements** Includes ground- and space-based measurements and related technology developments.	I	**Ground-based Radar Measurements of Debris and Meteoroids** Beampark experiments, observation and performance modelling for tracking and surveillance sensors, comparison of measurements and models. Processing of radar tracking data e.g. to reconstitute orbits of uncorrelated objects for operational collision avoidance and anomaly resolution.
				II	**Ground-based Optical Measurements of Debris and Meteoroids** High-altitude surveys for faint objects. Follow-up and catalogue maintenance of objects in high-altitude orbits. Development and operation of planning and processing software for optical measurements of artificial objects. Orbit determination and observations for anomaly resolution. Planning and performance analysis for optical space-based sensors.
				III	***In situ* Radar and Optical Measurements of Debris and Meteoroids** Space-based radar and optical detection techniques to characterise the small-particle environment. Development, flight and data evaluation.
		B	**Modelling and Risk Analysis** Includes population models for meteoroids and debris (current and future evolution), statistical and operational risk analysis in space and reentry survivability and safety analysis on the ground.	I	**Debris and Meteoroid Environment Models** Development and application of models for the characterisation of impact flux on orbital surfaces. Development and operation of databases on space objects, launch and space event information.
				II	**In-orbit Risks** Operational collision avoidance, conjunction detection and analysis, orbit refinement, avoidance manoeuvre optimisation. Statistical risk assessment and analysis of requirements for collision avoidance (delta-V, remaining risk) for mission planning.
				III	**Reentry Risks** Structural analysis to determine the survivability of spacecraft components under the influence of aerothermal and aerodynamic stress during controlled and uncontrolled reentries. Development of simulation models and models of the spacecraft geometry, materials. Computation of ground safety. Prediction of reentry windows (date and location) of risk objects from surveillance data.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
11	**Space Debris (cont.)**	C	**Debris Mitigation, Debris Environment Remediation and Protection** Includes identification, standardisation and verification of the implementation of mitigation measures and accompanying models, environment prediction modelling, active removal techniques as well as HVI test techniques, development and validation of numerical simulations, evaluation and modelling of materials for shielding.	I	**Space Debris Mitigation** Development of models and tools for the analysis of mitigation requirements for a space mission, which includes the prediction of orbital lifetime, fuel assessments, reentry survivability and mission survivability with respect to debris impacts, as well as standardisation of these activities.
				II	**Space Debris Environment Remediation** Long-term environment projections using models for traffic and mitigation actions. Identification of removal targets and evaluation of removal options.
				III	**Protection against Debris and Meteoroids** Testing, evaluation and development of HVI test techniques, development and validation of numerical simulations, evaluation and modelling of materials under HVI, impact damage data on S/C configuration, shield optimisation.
12	**Ground Station Systems and Networks** This domain covers all elements and knowhow required for engineering of the facilities that connect the space segment with control centres. The application range covers high-performance deep-space stations to networks of small ground stations.	A	**Ground Station System** Covering technologies and techniques related to the design of a ground station system and its constituent elements such as ground TT&C and payload data reception antenna systems using RF and optical techniques; transmit and receive radar and optical systems for ground-based space surveillance; TT&C, radar and optical signal and data processing.	I	**Advanced Ground Station Design Concepts** Covers design concepts for RF and optical ground stations for space communication and space surveillance applications.
				II	**Ground TT&C and Payload Data Reception Antenna Systems** Includes RF design, optical design, mechanical structures, servo-mechanisms, and tracking processes.
				III	**Microwave and Optical Active/Passive Systems** Includes all active components such as LNAs, detectors, HPAs, lasers, frequency converters, microwave sources, all passive components such as filters, switches, isolators, waveguides.
				IV	**TT&C, Radar and Optical Signal & Data Processing** Covers telemetry receivers, decoders and demodulators, telecommand modulators and encoders, telemetry data preprocessors, ranging subsystems and precise navigation techniques.
				V	**Frequency & Time Generation and Distribution** Covers all means of frequency generation such as atomic clocks, masers and crystal oscillators. Time reference generation and synchronisation. *(Note 12-E-V-1: Reference signals required for navigation, telecom and science applications are covered in 6-E-V)*

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
12	**Ground Station Systems and Networks (cont.)**	B	**Ground Communications Networks** Covering all technological aspects for TT&C and payload data distribution, related to the use of modern commercial-off-the-shelf ground communication technology/services, for providing cost/performance effective solutions to the operations of space missions.	I	**Advanced Ground Communication Networking Concepts** Covers new design concepts for data/communication in the ground segment.
				II	**Communication Network Technologies and Protocols** Covers issues related to communication and data exchange, including routing and modem issues as well as network protocols.
13	**Automation, Telepresence & Robotics** Covers the specification, development, verification, operation and utilisation of space automation systems. Such systems include (1) space robot systems (comprising both arm-based systems for inspection, servicing and assembly of space system infrastructure or payloads and mobile robots for surface exploration on celestial bodies) and (2) space laboratory automation and payload control systems in manned and unmanned missions. *(Note 13-1: Detailed mechanisms aspects are covered in TD15)*	A	**Applications and Concepts** Covers system aspects and innovative robotic concepts for missions.	I	**Planetary Exploration** Includes novel concepts for handling/assembly of surface infrastructure elements, novel aerobot concepts, novel robot concepts for exploration (including of asteroids), micro- and nano-rover concepts and swarms.
				II	**Orbital Systems** Includes automation of orbital infrastructure, or non-cooperative satellites, satellite design for robotic servicing, compound operation of arms on free-flying platforms, assembly and servicing of space structures in orbit, multi-robot cooperation.
		B	**Automation & Robotics Systems** Covers the detailed definition of robotic systems and subsystems, including technology developments dedicated to specific applications.	I	**Manipulation Systems** Includes robot arms, end-effectors and tools. (see Note 13-1)
				II	**Mobility Systems** Includes rovers, aerobots, underground and underwater explorers.
				III	**Payload Automation Systems** Covers all automation aspects of space laboratories.
		C	**Automation & Robotics Components and Technologies** Includes general purpose and specific Automation & Robotics (A&R) components and methods.	I	**Perception** Includes sensors and sensing methods (e.g. computer vision) which allow robots to perceive their environment and the state of the process they are controlling.
				II	**Control, Autonomy and Intelligence** Covers methods that allow robot systems to perform perception processing, understanding of the operating environment, motion planning and control, attention allocation, anticipation, activity planning, and reasoning about their own state and the state of other agents.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
13	**Automation, Telepresence & Robotics (cont.)**	**C**	**Automation & Robotics Components and Technologies (cont.)**	III	**Motion and Actuation** Covers the means that allow a robot to physically interact with its environment (e.g. limbs, joints, chassis, wheel units, balloon envelopes, propulsion units). (see Note 13-1).
				IV	**Robot-User Interfacing** Includes commanding and programming means (e.g. immersive systems, haptic devices) and methods that allow users to interact with an automation and robotics system. Includes teleoperation, telepresence, telescience.
				V	**Robot Ground Testing** Includes tools, methods and facilities that allow on-ground characterisation and verification of A&R systems.
14	**Life & Physical Sciences** Covers all technological aspects related to instrumentation in support of life and physical sciences, and for ensuring delivery of a complete system (instrument) technology. The objective is an optimised scientific return, the emphasis being rather on a consistent system philosophy than on the development of component technologies. Also includes the technologies and techniques relating to planetary protection, both sterilisation methods and technologies, and also system technologies needed to monitor contaminants.	A	**Instrumentation in Support of Life Sciences** Includes aspects of human physiology, biology, biotechnology, exobiology/planetary exploration.	I	**Sensors and Analytical Instrumentation** Covers the whole range of sensors and analytical instruments needed to monitor scientific experiments and to extract scientific data.
				II	**Imaging Diagnostics and Image Treatment Technologies** Includes the whole range from macroscopic imaging down to sub-microscopic imaging with the related image treatment technologies (contrast enhancement, compression etc.).
				III	**Cultivation, Processing and Bioprocessing** Starts from simple cultivation of cells and microorganisms and extends into bioreactor type cultivation including processing/ bioprocessing of materials for *in situ* resource utilisation.
		B	**Instrumentation in Support of Physical Sciences** Includes aspects of fluid science, material science, crystal growth, applied physics, planetary exploration.	I	**Sensors and Analytical Instrumentation** Starts at (high) temperature sensors and extends into complex analytical instruments such as Raman Spectroscopy and X-ray diagnostics tools.
				II	**Imaging Diagnostics and Image Treatment Technologies** Includes macroscopic and microscopic imaging and other (e.g. interferometric) imaging methods with the related problems of image acquisition storage, transfer and treatment. Image acquisition ranges from single shot to high-speed imaging (500 frames/s).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
14	**Life & Physical Sciences (cont.)**	B	**Instrumentation in Support of Physical Sciences (cont.)**	III	**Processing and Production** Includes low-volume processing of new materials and extends into processing and production utilising *in situ* resources in planetary exploration.
		C	**Applied Life Science Technology** Includes the application of advanced and new technologies of the life sciences to specific problems of planetary exploration, planetary protection and human long-term presence in space. *(Note 14-C-I-1: technologies related to sterilisation effects on materials are covered in 24-C-I)*	I	**Application of Human Physiology Technologies** Covers the application of human physiology technologies to human health monitoring/care and countermeasures for long duration spaceflight and includes radiation monitoring.
				II	**Bioburden/Biodiversity Monitoring** Covers all technologies required at spacecraft and facility level to comply with COSPAR planetary protection requirements.
				III	**Biobarriers** Covers all technologies required to isolate spacecraft subsystems with different bioburden levels. (Has to be tailored to organic and biological cleanliness required, and to the specific bioburden reduction process.)
				IV	**Dry Heat Sterilisation** Covers standard and non-standard dry heat bioburden reduction processes for subsystem and system (terminal process).
				V	**Low-Temperature Sterilisation** Covers gas and liquid sterilisation processes at low temperatures. Complementary to standard dry heat sterilisation.
				VI	**Precision Cleaning and Sterility** Covers cleaning processes to achieve high level of organic cleanliness and sterility. Required for sample acquisition and distribution systems, as well as for certain classes of sample return missions.
		D	**Applied Physical Science Technology** Includes the specific application of material science technology to use *in situ* resources for extraterrestrial production of components (e.g. heat and radiation shields etc.).	I	**Processing and Production** Includes the low-volume processing of new materials and extends into processing and production utilising *in situ* resources in planetary exploration.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms** All devices with moving parts (e.g. actuators, hold-down & release devices, pointing mechanisms, deployable booms, thrust vector control mechanisms); associated specific disciplines (such as tribology and pyrotechnics) and tools (such as mechanism and magnetic simulations).	A	**Mechanism Core Technologies** Building-block technologies used individually or in combination to provide a mechanism function.	I	**Actuator Technologies** Technologies to provide torque or force (e.g. electromagnetic motors, voice coils, piezo motors, shape memory alloy actuators, electroactive polymer actuators, spring actuators, paraffin actuators).
				II	**Dampers & Speed Regulator Technologies** Technologies to regulate the speed of a movable element or to damp mechanical loads (e.g. low melting point alloy regulator, fluid damper, mechanical damper, eddy current damper).
				III	**Motion Transformer Technologies** Technologies used to transform a motion (e.g. gears, pulleys and cables, harmonic drives, ball and roller screws).
				IV	**Motion & Force Sensor Technologies** e.g. switches, optical encoders, resolvers, strain gauge sensors, capacitive sensors, accelerometers.
				V	**Guiding Technologies** Technologies providing linear or rotational guiding functions (e.g. ball and roller bearings, journal bearings, magnetic bearings, ball joints, flexible guides).
				VI	**Sealing Technologies** Technologies providing a static or dynamic sealing function.
				VII	**Electrical Transfer Technologies** Technologies whose function is to transfer an electrical signal between two parts in relative motion, with or without contact (e.g. slip rings, roll rings, contactless technologies).
		B	**Non-Explosive Release Technologies** Non-pyrotechnic technologies used to release a force or torque (e.g. mechanical fuse, shape memory alloy, electromagnetic, paraffin).		
		C	**Exploration Tool Technologies** Tool technologies to acquire samples in exploration missions (e.g. drill bits, ultrasonic tools).		
		D	**Control Electronics Technologies** Technologies providing mechanism control (open and closed loop control electronics).		

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms (cont.)**	E	**MEMS Technologies** Micro-/nano-technologies providing a mechanism function (e.g. pointing, scanning). *(Note 15-E-1: Aspects related to quality are covered in TD23)*		
		F	**Tribology Technologies** Technologies related to the science of interacting surfaces.	I	**Lubrication Technologies** Technologies providing a lubrication function (e.g. solid lubricants, fluid lubricants, self-lubricating materials).
				II	**Material Surface Technologies** Technologies providing a specific material surface performance (e.g. coatings, heat treatment). *(Note 15-F-II-1: Issues related to material characterisation are covered in TD24)*
		G	**Mechanism Engineering** Specific mechanism engineering knowhow to develop space-related mechanisms.	I	**Engineering Disciplines** Specific engineering disciplines involved in the design and development of space mechanisms (e.g. motorisation sizing, micro-vibration analysis, functional tolerance budgets, multi-body dynamic analysis, tribology).
				II	**Engineering Tools** Specific tools used to support the design and development of space mechanisms (e.g. bearing sizing software, multi-body dynamic analysis software).
		H	**Pyrotechnic Technologies** Including development and testing of new materials, ignition methods, actuation and miniaturisation.	I	**Explosive Composition Technologies** Covers high-temperature survival and ageing characteristics; shock reduction technologies including testing.
				II	**Thermite Technologies** Cover applications of thermite heating to provide connection, disconnection, release, joining. Covers also provision of oxygen for life and other gases for pressure functions.
				III	**Reliability Determination for Non-Repeating Functions** Covers analysis techniques for valid estimates of reliability at required levels of confidence, definition and demonstration of test and analysis techniques for small samples.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms (cont.)**	**H**	**Pyrotechnic Technologies (cont.)**	IV	**Optical Ignition Technologies** Covers the development of components and systems for alternative to electrical ignition, with potential to increase safety by reducing sensitivity to electrical disturbance.
				V	**Advanced Electropyrotechnics** Covers the use of explosive foil initiators in order to reduce mass and cost and increase safety.
				VI	**Development of New Devices for Future Exploration and Exploitation Missions** Covers connection and disconnection of structures and fluid circuits, deployment of shields and shelters, seismic and exploration functions, anchoring, penetrating, sealing; for manned, robotic and automatic operation.
16	**Optics** Addresses technologies and techniques for systems, instruments and components, as well as design, engineering and verification methods, in the field of optics.	A	**Optical System Engineering** Covers definition, design and engineering of optical systems and payload/instrument architectures; covers also the evaluation and verification (by analysis and testing) of the optical design performances (including straylight).	I	**Overall Optical System Definition, Design and Engineering** Covers the definition, design and engineering of optical systems and subsystems and the conceptual definition of optical payload/instrument architectures.
				II	**Optical Design Performance Evaluation and Analysis** Covers evaluation and verification of optical design performances by analysis (e.g. optical models, Zemax, ASAP, CodeV) and/or testing (e.g. optics laboratory); includes evaluation of straylight and design of means for straylight suppression (e.g. baffles).
		B	**Optical Component Technology and Materials** Covers all techniques and technologies for design and manufacture of optical components (from micro/nanostructures to lightweight telescope mirrors of several metres' aperture) as well as of stable optical benches; includes component mounting technologies and special optical materials; covers the whole 'optical' spectrum from X-ray to far-infrared.	I	**Optical Components** Covers all technologies for refractive and reflective optical components such as (classical-bulk) filters, lenses, gratings, prisms, beam splitters, polarisers manufactured in conventional/ classical-bulk technology. Includes grinding/polishing techniques, special glass and substrates and coating technologies (radiation tolerant).
				II	**Micro-Optics Components, MOEMS, Optical Fibres and Passive Integrated Optics** Covers all passive optical components made in micro-/nanotechnology, such as diffractive elements, holographic elements, meta-material elements, micro-optic devices, micro-opto-electro-mechanical systems (MOEMS) like switches and dynamic gratings, optical fibres and integrated optics devices.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
16	**Optics (cont.)**	**B**	**Optical Component Technology and Materials (cont.)**	III	**Mirror and Telescope Technologies** Covers design, materials and manufacturing technologies for lightweight mirrors and telescopes (including structures and baffles) with apertures ranging from 10 cm to several metres, operating at X-ray, UV, visible, IR and far-IR wavelengths; includes monolithic mirrors, segmented mirrors, deployable telescopes, super-polishing and coating, adaptive optics and wavefront control.
				IV	**Optical Bench and Mounting Technologies** Covers design, materials and manufacturing technologies for stable, compact, lightweight optical benches operating at room temperature, but also down to cryogenic temperatures, and the development of stable component mounting and alignment technologies.
		C	**Optical Equipment and Instrument Technology** Optical equipment and instrument technology covers all techniques and technologies for the design, manufacture and test of optical equipment and instruments for imaging, spectroscopy, radiometry, sounding, remote sensing, metrology, ranging, illumination, free-space optical communications for applications in Earth observation, science and planetary research, telecommunications and navigation.	I	**Spectrometers, Imaging Spectrometers, Radiometers** Covers techniques and technologies for the design, manufacture and test of optical equipment and instruments for imaging, spectroscopy and radiometry, including Fourier-transform spectrometers.
				II	**Cameras, Illumination Devices, Displays** Covers techniques and technologies for the design, manufacture and testing of cameras and optical devices for illumination and display.
				III	**Laser Ranging and Imaging, Lidars and Altimeters** Covers techniques and technologies for the design, manufacture and testing of optical equipment and instruments for ranging, altimetry, 3D imaging (for GNC, planetary landers, RVD, rover navigation), atmospheric sounding, and remote sensing; includes tunable high-resolution filters.
				IV	**Interferometry, Aperture Synthesis and Optical Phased Arrays** Covers techniques and technologies for the design, manufacture and testing of optical equipment and instruments of very high-resolution based on interferometric methods, aperture synthesis and optical phased arrays, in particular for science missions and imaging/remote sensing from geostationary orbit.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
16	**Optics (cont.)**	C	**Optical Equipment and Instrument Technology (cont.)**	V	**High-Precision Optical Metrology** Covers techniques and technologies for the design, manufacture and testing of optical equipment and instruments for high-precision optical metrology in space (e.g. for formation-flying constellations), but also for on-ground verification of structures, mirror surfaces and telescopes.
				VI	**Optical Communications** Covers techniques and technologies for the design, manufacture and testing of optical equipment/subsystems and terminals for optical communications between satellites and between spacecraft and ground stations (e.g. feeder links, deep-space communications); includes specific technologies like quantum communications for secure links, cryptography and global key distribution.
17	**Optoelectronics** Covers the development and application of technologies combining photonics (i.e. circuits handling photons) with electronics to achieve given functions.	A	**Laser Technologies** Covers the technologies and techniques needed for the generation of coherent optical radiation.	I	**Laser Sources** Covers continuous wave (CW) lasers and pulsed diode-pumped bulk solid-state lasers (e.g. Nd:YAG, etc.), mode-augmented diode lasers for the near-infrared (NIR) spectral region (VCSEL, ECLD, etc.), mode-augmented quantum cascade lasers (QCL) and GaN for the mid-IR and visible spectral regions respectively, LEDs, diode-pumped rare Earth (RE) doped waveguide lasers, doped fibre lasers, etc.
				II	**Laser Pumping** Covers laser-diode arrays LDA (CW and QCW), high-power single-emitter (CW) diode sources and related pump-packaging issues, flash-lamp, solar pump, electron-beam, etc. Implementation of efficient spectral control of LDA emission.
				III	**Laser Oscillators and Amplifiers** Geometrical mode control of both stable and unstable resonator designs. Mode matching techniques and device technologies, etc. Q-switched and mode-locking techniques. Laser amplifier stages, coherent power control and combination. Amplifier designs for CW and pulsed applications; bulk amplifiers, flared semiconductor amplifiers, doped fibre amplifiers.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
17	**Optoelectronics (cont.)**	**A**	**Laser Technologies (cont.)**	IV	**Laser Frequency Control and Stabilisation** Covers laser cavity length control and tuning techniques, injection locking and seeding, for frequency control. Covers frequency stabilisation and locking techniques using optical stabilising reference cavities (OSRC) for phase control and the achievement of sub-Hz line widths and absolute frequency locking to narrow spectral features. Implementation of electronic-optical feedback techniques for linewidth reduction. Development and implementation of methods to reduce the Thermal Noise Limit (TNL) on SRC optics. Development and verification of novel methods to achieve sub-mHz linewidth emission.
				V	**Non-Linear Optics** Covers harmonic generation, non-linear crystals and poled waveguide materials, parametric conversion, multi-photon processes, stimulated light scattering, spatial laser beam cleaning using phase conjugated mirrors, saturable absorbers, etc.
		B	**Detector Technologies** Covers all the technologies and techniques needed for the detection of optical radiation.	I	**Visible Detectors (mostly Si based)** Covers single-pixel (photodiodes), linear and 2D arrays, CCD and CMOS image sensors (APS), APDs, APD arrays, SiPM arrays.
				II	**Infrared detectors. (NIR–FIR)** Covers both photon and thermal technologies, including MCT, InGaAs, III-V, QWIP, QDIP, T2SL, microbolometers, pyroelectrics.
				III	**UV, X-ray & Gamma-Ray Detectors** Covers Si, wide bandgap semiconductors, scintillators.
				IV	**Superconducting Detectors** Covers HEB, SINIS-junctions, heterodyne mixers, …
				V	**Superconducting Devices** Including low-temperature and high-temperature superconducting devices and sensors such as SQUIDs, Josephson-type junctions, gradiometers, etc.
				VI	**Focal Plane Technologies** Covers component technologies, integration, accommodation techniques, proximity electronics, interconnects (e.g. flex circuits), filters and windows.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
17	**Optoelectronics (cont.)**	C	**Photonics** Covers guided-wave optical technologies and techniques for handling optical signals, or to achieve specific functions for various applications.	I	**RF Photonics** Covers photonic devices for generation, handling and distribution of microwave signals on board satellites, frequency down-conversion, time delay, RF signal phase and amplitude control, optical beam-forming and distribution networks, onboard optical links & interconnects, etc.
				II	**Micro- & Nano-Photonics** Covers photonic IC technologies, hybrid and monolithic integration of active and passive functions in various material systems including silica and semiconductor materials. Silicon photonics for on-chip optical functions.
				III	**Fibre-Optic Sensors** Covers pressure, temperature and strain sensors, including interrogation units for satellites, platforms and launchers.
				IV	**Optical Atomic Clocks** Covers laser cooling and trapping techniques for atoms, ions and molecules, optical frequency combs based on mode-locked lasers and ultra-high-Q microcavities. Includes also fibre-optic and free-space optical frequency dissemination over large distances, subsystem integration and verification into clock systems, space qualification of subsystem elements.
				V	**Quantum Devices** Covers laser-cooled atom sensors including atom interferometers, magnetometers, photon confinement and trapping techniques leading to BECs, atomic-scale sensing devices, etc. Implementation of laser-cooled and coherent population trapping (CPT) and the technology required for its implementation; chip gas cells, etc.
18	**Aerothermodynamics** Dynamics of gases (physical processes & modelling), especially of atmospheric interactions with moving objects at high speed. It encompasses the whole spectrum from takeoff to landing, but also orbital ascent/descent, aeroheating and thermodynamics of propulsion.	A	**Numerical Methods** Includes engineering and computational fluid dynamics (CFD) techniques, both for internal and external flows, for the multidisciplinary design and analysis of Space Vehicles.	I	**Computational Fluid Dynamics (CFD)** Continuum and discrete particle models (including numerical algorithm and grid generation techniques) for multi-physics flow.
				II	**Engineering Techniques** Analytical, semi-empirical and parametric design tools.
				III	**Multidisciplinary Techniques** Coupling tools (including advanced optimisation algorithms) and/or databases of different technical disciplines.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
18	**Aerothermodynamics (cont.)**	B	**Ground-Based Facilities** Includes all types of wind tunnels and other test facilities for the design and analysis of space vehicles, both for internal and external flow.	I	**Cold Gas Facilities** Continuous and blow-down wind tunnels, ballistic ranges, etc.
				II	**Hot Gas Facilities** Arc-heated, piston driven, detonation driven, etc.
				III	**Dedicated Facilities** Contamination, hovering, base flow-jet interaction, etc.
		C	**Sensors and Measurement Techniques** Includes all types of measurement techniques for ground facilities and flight platforms, for the design and analysis of space vehicles, both for internal and external flow.	I	**Intrusive Measurements** Sensing technologies suitable for measurements in hostile environment – temperature, pressure, heat flux, etc.
				II	**Non-Intrusive Measurements** Multi-spectral infrared, laser spectroscopy, electron-beam, etc.
				III	**Wireless Measurements** Radio sensing, health monitoring, etc.
		D	**Flight Databases** Includes the informatics environment to conserve, retrieve and use flight data from experimental test beds and demonstrators, and their associated wind tunnel and CFD extrapolation to flight data.	I	**User Interface** Aspects related to tools and methods for data storage, handling and post-processing.
				II	**Informatics Environment** Aspects related to systems for data storage, handling and post-processing.
19	**Propulsion**	A	**Chemical Propulsion Technologies** Includes a wide range of technologies for propulsion systems, based on the use of chemical energy, relevant to the following major applications: (1) spacecraft onboard propulsion; (2) reusable or expendable launch vehicles/upper stage propulsion; (3) reentry manoeuvring propulsion systems.	I	**Liquid Propulsion Systems** Includes cold gas, mono- and bipropellant, onboard systems, cryogenic and LOX/hydrocarbon launch vehicle systems.
				II	**Solid Propulsion Systems** Includes from microthrust systems up to launch vehicle boosters.
				III	**Air-Breathing and Hybrid Propulsion Systems** Includes ramjets, scramjets, rocket based cycles.
		B	**Electric Propulsion Technologies** Includes propulsion systems and components that use electrical energy (solar or nuclear), classified according to the following major applications: (1) spacecraft onboard propulsion; (2) upper stage propulsion.	I	**Electrostatic Systems** Includes systems based on Hall-effect thrusters, gridded ion engines, field emission thrusters.
				II	**Electrothermal Systems** Includes systems based on resistojets, arcjets and power-augmented catalytic thrusters.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
19	**Propulsion (cont.)**	**B**	**Electric Propulsion Technologies (cont.)**	III	**Electromagnetic Systems** Includes systems based on magneto-plasma-dynamic thrusters and pulsed plasma thrusters.
		C	**Advanced Propulsion** Includes a wide range of non-classical propulsion systems, for both spacecraft and launchers/upper-stages, and the technology field of breakthrough propulsion physics.	I	**Solar Thermal Propulsion Systems**
				II	**Nuclear Propulsion Systems**
				III	**Solar Sailing Propulsion Systems**
				IV	**Tethered Propulsion Systems**
				V	**New Concepts** Including laserbeamed propulsion, Lorentz force accelerators, cryosolids, etc.
		D	**Supporting Propulsion Technologies and Tools** Includes several and tools that are used in support of the development, qualification, integration and monitoring of propulsion systems. These tools and technologies, although similar in scope and classification, might differ substantially depending on their use for chemical, electrical or advanced propulsion.	I	**Modelling** Includes propulsion system design tools, thruster and engine performance prediction tools, propulsion system/space vehicle interaction tools and related orbit/trajectory definition tools.
				II	**Testing and Diagnostics** Including facilities and diagnostic tools for ground performance, qualification and acceptance tests of propulsion systems; onboard propulsion diagnostics and health monitoring systems.
				III	**Propellants** Including technologies for production, storage, transportation and characterisation of solid, liquid or gaseous propellants.
				IV	**Ground Support Equipment (GSE)** Including all mechanical, fluid and electrical ground support systems dedicated to a propulsion system integration, testing, loading and launch preparation.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures** Technologies and methodologies related to design, analysis, manufacture and test of structures and mechanical systems for S/C, planetary infrastructures, habitats, launchers and reentry vehicles. Includes metallic and non-metallic structures such as advanced deployable structures (solar array, radiator, shield and antenna structures), highly-loaded structures, highly-stable structures and hot structures.	A	**Structural Design and Verification Methods and Tools** This includes all technologies related to the development and implementation of mechanical design tools, analysis tools and methodologies, testing tools and methodologies, load measurements and evaluation techniques etc.	I	**S/C Design and Design Tools** Including CAD tools and methodologies.
				II	**Analysis Tools and Methodologies** Including structural verification tools and methodologies (acoustics, damage tolerance, thermoelastic, deployment simulations, composite structures …).
				III	**Testing Tools and Methodologies** Including test data storage tools, test data evaluation tools, test prediction tools.
				IV	**Inflight/In-orbit Loads and Vibration Measurement Techniques** Including sensors, integration, data recording/downloading, data evaluation.
		B	**High-Stability and High-Precision S/C Structures** Covers all technologies related to such structures, including advanced material applications, as well as manufacturing and verification aspects.	I	**Advanced Material Technologies for Stable Structures** Including manufacture of stable structures, structural verification, failure analysis, definition of structural allowables etc.
				II	**Joining and Mounting Technologies** Including interfacing to other structures, verification of interfaces for high-stability and high-precision structures.
				III	**Thermoelastic Stability Verification Technologies** Including design, analysis and test aspects.
		C	**Inflatable and Deployable Structures** (shields, antennas, booms, solar arrays, airbags and inflatable landing systems etc.) Covers all technologies related to such structures, including materials, deployment simulations, damping, active control and verification methodologies.	I	**Design and Verification Technologies** Including design tools, deployment simulation, test methodologies, combined verification methodologies.
				II	**Structural Material Concepts** Including material testing, laminate/membrane design, in-orbit curing aspects.
				III	**Joining Technologies** Including design and verification of joints (both flexible-to-flexible and flexible-to-rigid) for inflatable and deployable structures.
		D	**Hot Structures** Covers all technologies related to such structures, including related material developments, coatings and verification methodologies.	I	**Design and Verification Technologies for Ceramic Structures** Including manufacturing aspects, detailed design aspects, analysis and test aspects, static, dynamic, thermoelastic.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures (cont.)**	**D**	**Hot Structures (cont.)**	II	**Design and Verification Technologies for Metallic Structures** Including manufacturing aspects, detailed design aspects, analysis and test aspects, whether static, dynamic, or thermoelastic.
				III	**New Advanced Hot Structures Materials** Including development and structural application of advanced materials such as UHT materials.
				IV	**Joining technologies** Covering all aspects related to joining of hot structures, e.g. fasteners, brazing and other methods. Also includes verification methods.
				V	**Health Monitoring Technologies** Including sensors, data recording, data evaluation etc.
		E	**Active/Adaptive Structures** Covers all technologies related to the development and application of such structures, for dynamic control of flexible structures, noise reduction, load reduction, active and passive damping. Includes sensor and activator developments, structural and system integration and control logics.	I	**Sensor/Actuator Technologies** Including sensor/actuator developments e.g. electroactive polymers (EAP), piezo patches, fibres. *(Note 20-E-I-1: Detailed mechanisms aspects are covered in TD15)*
				II	**Technologies for Structural Integration** Including the application of various sensor/actuator combinations.
				III	**Data Acquisition and Control Logic Technologies Related to Structural Dynamics** Covering multi-body dynamics analysis tools and methodologies.
				IV	**Design and Verification Tools and Methodologies** Including detailed analysis and test tools.
		F	**Damage Tolerance and Health Monitoring** Includes all technologies related to the development and implementation of damage tolerance and health monitoring tools, methodologies and hardware, including fatigue, fracture control, non-destructive inspection (NDI) and sensor developments.	I	**Non-Destructive Inspection Technologies** Including the development of new methodologies and related hardware, application in space programmes.
				II	**Structural-Health-Monitoring Sensor Technologies** Including sensor development, structural integration etc.
				III	**Fracture Control Tools and Methodologies** Including numerical tools, detailed analysis methodologies, e.g. for non-linear applications, damage tolerance for composites and ceramics.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures (cont.)**	G	**Launchers, Reentry Vehicles, Planetary Vehicles** (ascent, entry, …) Includes all related technologies for the development of vehicle primary and secondary structures, control surfaces, shields etc.	I	**Technologies for Design and Verification of Advanced Primary Structures** Including structural concepts for highly-loaded components, manufacturing methodologies e.g. fibre placement, RTM etc.
				II	**Advanced Tank Design and Verification Technologies** Including metallic and composite tanks, interfaces to primary structure, HMS, NDI, damage tolerance approaches, etc.
				III	**Landing Attenuation Technologies** Including airbag technologies, landing legs, application of crushable materials, foams etc.
				IV	**Control Surfaces, Design and Verification Technologies** Including design with ceramics as well as advanced metallic alloys, combined mechanical–thermal test methodologies etc.
		H	**Crew Habitation, Safe Haven and EVA suits** Includes all technologies for the development of related primary and secondary structures, shields etc.	I	**Habitation Primary and Secondary Structure Technologies** Covers environmental shields, design and verification technologies.
				II	**EVA Suits, Mechanical Aspects** Including design of load-/pressure-carrying elements, interface design between elements, structural material aspects, meteoroid/debris impact shielding aspects.
		I	**Meteoroid and Debris Shield Design and Analysis** Includes the development of related analysis and test tools and methods, shield developments, damage assessments etc.	I	**Tools and Methodologies for Design and Verification of Meteoroid & Debris Shields** Covers numerical tools, materials models, shield test methods, gas guns, shaped charges, data acquisition technologies.
		J	**Advanced Structural Concepts and Materials**	I	**Design and Verification Technologies** Covers structures manufactured from novel materials (nanotube reinforced, foams, self-healing materials etc.).
21	**Thermal** Covers all technologies needed for the thermal control of space systems.	A	**Heat Transport Technology** Covers all technologies associated with heat transport, whether in the single phase or using the latent heat in two-phase systems.	I	**Heat Pipes** Covers all technologies related to heat pipes, e.g. constant conductance, variable conductance and heat pipe diodes.
				II	**Capillary-Driven Loops** Covers all technologies related to capillary-driven two-phase heat transport loops, including Capillary Pumped Loops (CPLs) and Loop Heat Pipes (LHPs).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
21	**Thermal (cont.)**	A	**Heat Transport Technology (cont.)**	III	**Mechanically-Pumped Two-Phase Loops** Covers all elements and associated technologies for mechanically-pumped two-phase heat transport loops.
				IV	**Mechanically-Pumped Single-Phase Loops** Covers all elements and associated technologies for mechanically-pumped single-phase heat transport loops.
				V	**Heat Switches** Covers all elements and technologies for heat switches, e.g. based on LHPs or mechanically driven.
		B	**Cryogenics and Refrigeration** Covers all technologies associated with transferring heat from lower to higher temperature levels and cooling by evaporation of stored cryogens.	I	**Refrigeration and Heat Pumps** Covers all refrigeration technologies required for temperature control of items in a near-room-temperature environment, including also heat pumps.
				II	**Cryo-Coolers** Covers all active cryo-machinery and associated technologies for cooling to cryogenic temperatures (down to 1K).
				III	**Passive Coolers and Stored Cryogens** Covers all technologies related to non-active cooling (e.g. radiators, cryostats).
				IV	**Sub-Kelvin Coolers** Covers all technologies required to provide cooling below 1K.
		C	**Thermal Protection** Covers all technologies associated with thermal protection and insulation systems for atmospheric entry.	I	**Ablative Systems** Covers all technologies providing thermal protection based on chemical and/or physical reactions.
				II	**Reusable Systems** Covers thermal protection technologies for multiple applications on reentry vehicles.
		D	**Heat Storage and Rejection** Covers all technologies associated with heat storage and rejection using coatings, insulation, thermal capacitors and radiators.	I	**Coatings and Insulation** Covers all technologies for achieving thermal control surfaces and insulation.
				II	**Heat Storage** Covers all types of thermal capacitors, e.g. phase-change materials.
				III	**Radiators** Covers all technologies associated with radiative interfaces between the system and its environment, including louvres.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
21	**Thermal (cont.)**	E	**Thermal Analysis Tools** Covers all software tools and methods for the design and verification of space systems.	I	**Thermal Software Tools** Covers all software used for system-level analysis in the thermal area.
				II	**Thermal Data Exchange** Covers all protocols, tools and methods for thermal data transfer from one software environment to another.
				III	**Thermal Analysis Methods** Covers all analytical and numerical methods in relation with the development and application of software tools for design and verification.
22	**Environmental Control & Life Support (ECLS) and *In Situ* Resource Utilisation (ISRU)** Covers all technologies for controlling, maintaining and supporting human presence in space and the utilisation of local resources.	A	**ECLS** Covers all technologies for controlling, maintaining and supporting human presence in non-terrestrial environments, such as regenerative (recycling) technologies for air, water and waste, food production and preparation, environmental monitoring and control, including habitability issues.	I	**Environmental Control and Monitoring** Covers all technologies related to air, water and food quality monitoring and control with respect to microbial and chemical contaminants.
				II	**Regenerative Life Support** Covers all technologies related to air and air revitalisation, water and waste recycling and food preparation and production, using physico-chemical and biological processes.
				III	**Habitability** Covers all technologies needed for design and implementation of a human habitat, aiming for crew wellbeing, crew motivation and optimum performance, including definition of key psychological factors.
				IV	**Integrated ECLS** Covers all aspects and associated technologies for integrated human habitats and life support systems, including ground-based testbeds and overall simulation tools and methods.
		B	**ISRU** Covering the technological aspects related to the use of indigenous materials at the site of an interplanetary mission for the production of resources such as propellants (e.g. methane, oxygen), reactants for fuel cells (e.g. carbon monoxide, oxygen) or fluids/gases for life support.	I	**ECLS Consumables** Covers all technologies for collecting and processing fluids and gases to be used as consumables for ECLS in human habitats (e.g. oxygen, hydrogen, nitrogen, water).
				II	**Fuels** Covers all technologies for collecting and processing fluids and gases to be used as consumables for propulsion and energy production.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
22	**ECLS and ISRU (cont.)**	B	**ISRU (cont.)**	III	**Storage and Distribution** Covers all technologies required for storing and distributing fluids and gases.
23	**EEE Components and Quality** Covers technologies related to the design, production and testing of EEE components which meet the performance and reliability requirements for use in onboard electric/electronic systems. *(Note 23-1: This technology domain is concerned with quality issues; specific design issues are covered by the respective TD)*	A	**Methods and Processes for Product Assurance of EEE Components, including Radiation Hardness Assurance** For determining and enhancing technology/component reliability and suitability for flight applications. Definition of radiation hardness assurance (RHA) requirements, modelling of particle interaction with matter and resulting radiation effects in EEE components (including simulation of component parameter degradation), characterisation of radiation effects in terms of technology and design-dependent basic mechanisms, radiation hardening/mitigation and radiation verification testing, including definition of irradiation test facility requirements and dosimetry.	I	**Evaluation and Testing** Includes the development of laboratory techniques and test methods for characterisation, evaluation, qualification, derating, end-of-life, failure analysis and procurement of space components.
				II	**Radiation Hardening** Process hardening, design hardening, mitigation techniques, verification and validation.
				III	**Design and Development** Development and design of components adapted to the requirements for space applications and capable of meeting space component qualification requirements.
				IV	**Modelling** Simulation of EEE component responses to radiation at semiconductor level, including simulation and prediction of EEE component parameter degradation.
				V	**RHA Process** Definition of RHA requirements and development of irradiation test method/guidelines.
				VI	**Irradiation Test Facilities** Definition of irradiation test facility requirements covering particle species, energy, flux, beam size, uniformity and accuracy. Definition of dosimetry and dosimetry accuracy. Definition of all interfaces (mechanical and electrical) to enable irradiation testing of EEE components.
		B	**EEE Component Technologies** Covers the component technologies most commonly evaluated using the processes in 23-A.	I	**Passive Components** Capacitors, inductors, resistors, crystals, magnetics, switches, wires, cables, connectors, piezo actuators, heaters, harnesses, non-integrated electro-mechanical components. RF passive components such as isolators, circulators, etc. are also addressed.
				II	**Silicon-Based Components** Discretes, analogue, digital and mixed signal technologies and device types across all integration levels and functional complexity ranges in bipolar and MOS technologies.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
23	**EEE Components and Quality (cont.)**	B	**EEE Component Technologies (cont.)**	III	**RF Microwave and Millimetre Wave Components** Discretes and MMIC components including RF-CMOS, GaAs, SiGe, InP technologies, packaging and RF passive components.
				IV	**Optoelectronic Active and Passive Components** Optical and near-optical sensors, detectors, laser diodes, fibre optical connectors, optical assemblies and associated passive components.
				V	**Hybrids and Micropackaging** Thick and thin film hybrid technologies, microwave hybrid circuits, DC–DC converter technologies, crystal oscillators, multichip modules, system-on-a-chip (SOC), 3D stacking and interconnect technologies, IC packaging technologies, RF and MMIC packaging and subassemblies.
				VI	**Power Components** Very-high-voltage MOSFETS, IGBT, SiC, GaN power devices, power including for realisation of high-performance DC–DC power conversion transistors and thermal management components.
				VII	**Wide Band Gap Technologies** SiC, GaN and Diamond for advanced MMIC applications and harsh environment sensor technologies and for realisation of high-performance DC–DC power conversion transistors.
				VIII	**Micro Electro Mechanical Systems (MEMS)** Evolving range of technologies and applications including RF MEMS, pressure sensors, AOCS sensors, MOEMS, actuators, etc.
				IX	**Nanotechnology in Microcircuits** Application of carbon nanotubes, nanofibres, innovative nanomaterials to microcircuit improvement.
24	**Materials and Processes** Covers the materials mechanics and processes, their physical and chemical behaviour and the interaction with the operational environment through the S/C and ground infrastructure lifecycle. Furthermore, all manufacturing processes are covered.	A	**Novel Materials and Materials Technology** Includes materials not yet used in space but presenting potential interest.	I	**Material Assessment** Including basic properties, possibility to scale-up, limitations.
				II	**Nanotechnology** Covering development, manufacture and test of nanotubes, nanofibres, nanocoatings.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Processes (cont.)**	B	**Materials Processes** Materials manufacturing processes and fabrication techniques.	I	**Joining** Including glueing, bonding, welding, brazing, soldering, fastening, repairing. *(Note 24-B-I-1: technologies related to the joining of high-stability structures are covered in 20-B-II; technologies related to the joining of inflatable and deployable structures are covered in 20-C-III; technologies related to the joining of hot structures are covered in 20-D-IV.)*
				II	**Coating** Including development, manufacture and test of paints, conformal coatings, organic and inorganic coatings, thermo-optical coatings, thermal control materials, optical materials, sol-gel coatings, ALD, oxidation protection, finishes.
				III	**Characterisation and Feedback** Covers all aspects related to thermo-physical/ mechanical/chemical properties, long-term ageing effects.
				IV	**Advanced Materials Manufacture** Covers manufacturing aspects related to CFRP, ceramics, CMC, MMC, foams, functionally-gradient materials, sol-gel processed materials, near-net-shape processing route, PVD & CVD processes, ISRU processes for solid materials manufacture, nanotechnology aspects of materials…
		C	**Cleanliness and Sterilisation** Includes the techniques, tests and technologies to ensure and verify that the hardware fulfils the requirements in terms of contamination, sterilisation and degradation in a broad sense.	I	**Sterilisation of Materials** Effect of sterilisation on materials and assemblies, compatibility of materials with sterilisation techniques. *(Note 24-C-I-1: Technologies related to verification of the bioburden reduction process are covered in 14-C-IV to 14-C-VI).*
				II	**Control of Molecular Contamination** Outgassing of materials, cleanliness monitoring techniques, contamination transfer processes, effects on performance, mitigation, surface contamination, … Laser-induced contamination, photofixation of contamination.
				III	**Control of Particulate Contamination** Includes contamination transfer processes, effects on performance, mitigation, protection, cleanroom monitoring.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Processes (cont.)**	C	**Cleanliness and Sterilisation (cont.)**	IV	**Control of Bio-Corrosion, Biocides, Plasma Corrosion etc.** Addresses the degradation of materials interacting with an atmosphere, including degradation resulting from an inhabited atmosphere.
				V	**Contamination Modelling and Lifetime Prediction of Material Behaviour** Modelling and lifetime prediction by the interaction of materials/environment with contamination.
		D	**Space Environmental Effects on Materials and Processes**	I	**Interaction of Materials with the Space Environment** Electromagnetic radiation from EUV to FIR, X-rays, particle radiation, vacuum, atomic oxygen, charging, contamination, synergistic effects, dust & particles, planetary gases…
				II	**Interaction of Materials with the Ground Environment** Covering issues such as storage, logistics, corrosion, swelling.
				III	**Interaction of Materials with the Inhabited Environment** Addressing safety- and performance-related issues affecting the inhabited environment such as toxicity, flammability, ….
		E	**Modelling of Materials Behaviour and Properties**	I	**Microstructural and Nanostructural Characterisation of Materials**
				II	**Modelling of Thermomechanical Processes of Materials including Lifetime Predictions**
				III	**Characterisation, Modelling and Testing of Fracture Mechanics**
				IV	**Thermal Analysis of Materials** Covers characterisation of the functional properties of materials from cryogenic to reentry/launcher temperatures.
		F	**Non-Destructive Inspection** Includes development of test and verification methods.	-	-
		G	**Material and Process Obsolescence**	I	**Regulation and legislation-based obsolescence** Addresses the materials and manufacturing process availability and limitations due to environmental regulations and export regulations (e.g. REACH, RoHS, ITAR, etc.).
				II	**Scarce Materials** Due to production stop, bankruptcy, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Processes (cont.)**	H	**Materials for Electronic Assembly**	I	**Printed Circuit Board Technologies**
				II	**Surface Mount Technologies**
			Materials for Electronic Assembly (cont.)	III	**Verification of Electronic Assemblies**
25	**Quality, Dependability and Safety** Covers the quality, reliability, availability, maintainability and safety of space systems and their constituents (hardware, software and the human element). It also addresses methods and tools for the assessment and management of technical risks associated with space systems and their operations.	A	**System Dependability and Safety** Addresses the reliability, availability, maintainability and safety of the entire space system.	I	**Dependability and Safety Methods & Tools** Covers methods and tools to achieve mission success and hazard control.
				II	**Technical Risk Management Techniques** Covers the identification, evaluation, mitigation and acceptance of risks.
		B	**Software Quality** Addresses the quality of the software development process and the resulting software products.	I	**SW Process Quality Techniques** Covers the techniques to assure the quality of the software development process.
				II	**SW Product Quality Techniques** Covers the evaluation and certification of the quality of the software products.
		C	**Product and Quality Assurance**	I	**Product Assurance Processes for Flight and Ground Systems** Covers the coordination and integration of PA disciplines (QA, safety, dependability, EEE parts, materials, mechanical parts, processes, software PA), auditing, critical items, configuration management, alerts, document and data control, nonconformance control and quality records.
				II	**Quality Assurance Processes for Flight and Ground Systems** Covers assurance of design, manufacture, assembly, integration, testing, procurement, recurring production, training, inspections, traceability and standards.
26	**OTHERS** Please contact the TEC-T office at ESTEC if you need to include additional technologies not covered in this document.				

Appendix A – Technology Domain Responsibles

The following table lists the contact points in ESA for the Technology Domains defined in sections 2 and 3.

TD ID	TD TITLES	TD CONTACT POINTS IN ESA	AFFILIATION
01	Onboard Data Systems	Philippe Armbruster	TEC-ED
02	Space System Software	Jean-Loup Terraillon Nestor Peccia Pier Giorgio Marchetti	TEC-SWE HSO-GI EOP-GSR
03	Spacecraft Electrical Power	Henri Barde	TEC-EP
04	Spacecraft Environments & Effects	Eamonn Daly	TEC-EES
05	Space System Control	Alain Benoit	TEC-EC
06	RF Systems, Payloads & Technologies	Riccardo De Gaudenzi	TEC-ET
07	Electromagnetics Technologies & Techniques	Cyril Mangenot	TEC-EE
08	System Design & Verification	Joachim Fuchs Benoit Laine	TEC-SWM TEC-MTV
09	Mission Operation and Ground Data Systems	Nestor Peccia	HSO-GI
10	Flight Dynamics and GNSS	Frank Dreger	HSO-GF
11	Space Debris	Heiner Klinkrad	HSO-GR
12	Ground Station Systems and Networks	Klaus-Juergen Schulz	HSO-GS
13	Automation, Telepresence & Robotics	Gianfranco Visentin	TEC-MMA
14	Life & Physical Sciences	Robert Lindner	TEC-MMG
15	Mechanisms	Gerard Migliorero	TEC-MSM
16	Optics	Luca Maresi	TEC-MMO
17	Optoelectronics	Zoran Sodnik	TEC-MME
18	Aerothermodynamics	José Longo	TEC-MPA
19	Propulsion	Giorgio Saccoccia	TEC-MP
20	Structures	Rafael Bureo	TEC-MSS
21	Thermal	Olivier Pin	TEC-MTT
22	ECLS and ISRU	Christophe Lasseur	TEC-MMG
23	EEE Components & Quality	Ralf de Marino Laurent Marchand	TEC-QE TEC-QTC
24	Materials & Processes	Mikko Nikulainen	TEC-QT
25	Quality, Dependability and Safety	Luigi Bianchi	TEC-QQD
26	OTHERS		TEC-T

Appendix B – Differences between Technology Tree Versions 2.1 and 3.0

Issue 3.0 of the Technology Tree (TT) now contains:

- 26 TDs (26 in issue 2.1)
- 101 TSs (92 in issue 2.1)
- 320 TGs (274 in issue 2.1)

The total number of entries for issue 3.0 is therefore 447. TT issue 2.1 contained 392 entries, and issue 1.1, 411 entries. An outline of the changes introduced in this latest revision is as follows:

- 47 entries have been added
- 44 entries have an updated title
- 110 entries have an updated description
- 7 entries have been moved inside the TT
- 3 entries have been deleted
- 9 entries have been split into more than one entry
- 6 entries have been merged

In more detail, the major changes that have been introduced are:

- System Design & Verification (TD8) has undergone major rewriting
- Space Debris (TD11) was previously only defined down to TS level, TGs have now been added
- Pyrotechnics has been moved from Structures (TD20) to Mechanisms (TD15)
- Aerothermodynamics (TD18) has undergone extensive restructuring and rewriting
- Space System Control (TD5) has had new TSs added and also been rewritten
- Several new TSs and TGs have been introduced in EEE Components & Quality (TD23), Materials & Processes (TD24) and Quality, Dependability and Safety (TD25)
- A large coordination effort has been undertaken to clarify the split between RF Payload Systems (TD6), Flight Dynamics and GNSS (TD10), and Ground Station Systems and Networks (TD12)

The following table gives a mapping matrix from the entries of issue 2.1 to the entries of issue 3.0. Please note that, in the table, when an entry of issue 3.0 is followed by a * it means that more branches were added and therefore a direct match between issues 2.1 and 3.0 is not possible (example: 11-A from 2.1 now has several subgroups in 3.0, therefore 11-A is now 11-A*).

TT2.1			**TT3.0**
5	A	I	5-A-I
		II	5-A-II
	B	I	5*
		II	5*
		III	5-B-III
10	A	I	10-A-I, 10-A-II
		II	10-A-II
		III	10-A-II
		IV	10-A-III
	B	I	10-B-I
		II	10-B-II
11	A		11-A*
	B		11-B*
	C		11-C*
18	A	I	18-A-I
		II	18-A*
		III	18-A*
		IV	18-A*
	B	I	18-B*
		II	18-B*
		III	18-B*
		IV	18-B*
	C	I	18-C*
		II	18-C*
	D	I	18-D*
		II	18-D*
	K	I	15-H-I
		II	15-H-II
		III	15-B
		IV	15-H-IV
		V	15-H-V
		VI	15-H-VI
		VII	15-H-III

Appendix C: Acronyms

A&R	Automation & robotics
AIT	Assembly, integration and test
AIV	Assembly, integration and verification
ALD	Atomic layer deposition
AOCS	Attitude & orbit control system
APD	Avalanche photodiode
APS	Active pixel sensor
ASIC	Application specific integrated circuits
ASSP	Application specific standard products
BCR	Battery charge regulator
BDR	Battery discharge regulator
BEC	Bose-Einstein condensate
CAD	Computer-aided design
CCD	Charge-coupled device
CFD	Computational fluid dynamics
CFRP	Carbon-fibre-reinforced plastic
CMC	Ceramic matrix composite
CMG	Control moment gyroscope
CMOS	Complementary metal oxide semiconductor
COSPAR	COmmittee on SPAce Research
CPL	Capillary pumped loop
CPT	Coherent population trapping
CSOS	Complex System of Systems
CVD	Chemical vapour deposition
CW	Continuous wave
DC	Direct current
DRS	Data relay satellite
DSP	Digital signal processor
EAP	Electroactive polymer
ECLD	External cavity laser diode
ECLS	Environmental control & life support
EEE	Electric, electromechanical & electronic
EGNOS	European geostationary navigation overlay service
EGSE	Electrical ground support equipment
EMC	Electromagnetic compatibility
EO	Earth observation
EPC	Electronic power converter
ESD	Electrostatic discharge
ESTEC	ESA's European Space Research and Technology Centre
ESTER	European Space Technology Requirements database
EUV	Extreme ultraviolet
EVA	Extra-vehicular activity

FD	Flight dynamics
FIR	Far-infrared
FOG	Fibre-optic gyro
FPGA	Field programmable gate array
GNC	Guidance, navigation & control
GNSS	Global navigation satellite system
GPS	Global positioning system
GSE	Ground support equipment
HCI	Human computer interface
HEB	Hot-electron bolometer
HMS	Health monitoring system
HPA	High-power amplifier
HRG	Hemispherical resonator gyro
HVI	High-velocity impact
HW	Hardware
IC	Integrated circuit
IGBT	Insulated gate bipolar transistor
IMU	Inertial measurement unit
I/O	Input/output
IP	Intellectual property
ISRU	*In situ* resource utilisation
ITAR	International Traffic in Arms Regulations
LDA	laser-diode array
LED	Light-emitting diode
LEO	Low Earth orbit
LHP	Loop heat pipe
LNA	Low noise amplifier
LOX	Liquid oxygen
M&C	Monitoring & control
M&D	Meteoroid and Debris
MCS	Mission control systems
MCT	Mercury cadmium telluride
MEMS	Micro electro mechanical systems
MEO	Medium Earth orbit
MMC	Metal matrix composite
MMIC	Monolithic microwave integrated circuit
MOEMS	Micro-opto-electro-mechanical systems
MOS	Metal oxide semiconductor
MOSFET	Metal oxide semiconductor field effect transistor
NCO	Numerically-controlled oscillator
NDI	Non-destructive inspection
Nd:YAG	Neodymium-doped yttrium aluminum garnet

NIR	Near-infrared
OMG	Object management group
OSRC	Optical stabilising reference cavities
PA	Product assurance
PCU	Power conditioning unit
PDM	Payload data modulator
PDU	Power distribution unit
PPU	Power processing unit
PVD	Physical vapour deposition
QA	Quality assurance
QCL	Quantum cascade lasers
QCW	Quasi-continuous wave
QDIP	Quantum dot infrared photodetector
QWIP	Quantum well infrared photodetector
RE	Rare Earth
REACH	Registration, evaluation, authorisation and restriction of chemical substances
RF	Radio frequency
RFC	Radio frequency compatibility
RHA	Radiation hardness assurance
RoHS	Restriction of hazardous substances
RTM	Resin transfer moulding
RVD	Rendezvous and docking
SAR	Solar array regulator
SAR	Synthetic aperture radar
S/C	Spacecraft
SOC	System-on-a-chip
SQUID	Superconducting quantum interference device
SRC	Stabilising reference cavity
SW	Software
TD	Technology domain
TDR	Technology domain responsible
TECNET	ESA Technology Network
TG	Technology group
TNL	Thermal noise limit
TS	Technology subdomain
TT	Technology tree
TT&C	Telemetry, tracking and command
TWT	Travelling wave tube
UHT	Ultra-high temperature
VCO	Voltage-controlled oscillator
VCSEL	Vertical cavity surface-emitting lasers

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