Esterline CMC Electronics

AEEC 2013 Presentation to the Airlines and the Aviation Industry

Multi-Frequency/Multi-Constellation (MFMC) GNSS Receivers Value for Aviation and Airlines

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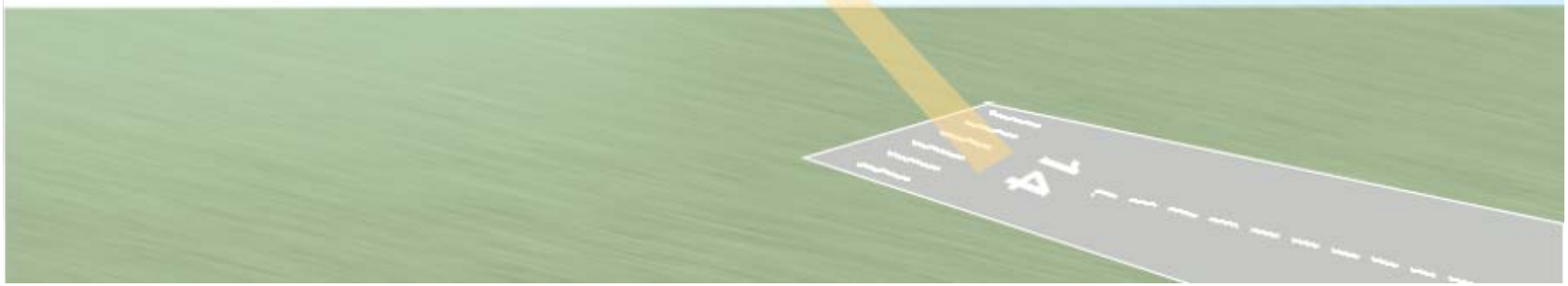
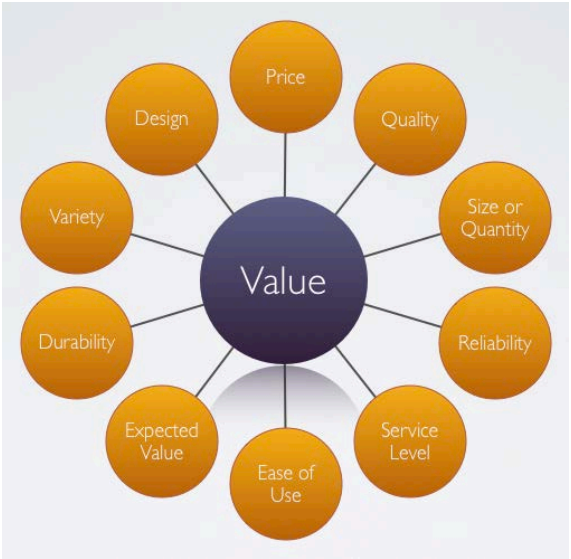
Agenda

- Introduction… What airlines see as value
- GPS, SBAS, GBAS… What we have today
- Brief Overview of Today's Technology
- Future Airline Business Needs
- Current and Future Mandates
- Future GNSS and Their Signals
- Future GNSS Receivers
- MCMF Receiver Technology and Complexity



Introduction

- Avionics: what value proposition to the Airlines?
  - Will new avionics reduce operating costs?
    - Operation costs – fuel consumption
      - Support more efficient (RNP) routes
      - LPV & GLS approaches (no delays)
    - Single type of equipage used globally
    - Minimize training costs
  - Will avionics support new mandates?
    - **ADS-B mandates (2020 or earlier)**
    - **GLONASS mandates (2017)**
    - Reducing use of ILS is a possible mandate
    - Any future state-imposed GNSS mandate
    - Jamming and spoofing detection mandates
  - Will avionics enable business expansion?
    - RNP, LPV, and GLS operations may open new routes and destinations, may increase passenger traffic (= new revenue).



Acquisition of (new) avionics justified when the business benefits.

GPS, SBAS, GBAS & GLONASS: What's available today

	GPS	SBAS	GBAS	GLONASS
COST REDUCTION				
"on-schedule" SIDS & STARS	✓	✓	✓	✓
Support RNP & more efficient routes	✓ 0.3?	✓ 0.1	✗	✓ 0.3?
CURRENT MANDATES				
ADS-B	? SA-AWARE	✓	✗	?
GLONASS	✗	✗	✗	✓
Support New Destinations/Business				
Terminal Area support (availability>99.999%)	✗	✓	✗	✗
Non-Precision Appr (availability>99.999%)	✗	✓	✓	✗
CAT – I	✗	✓	✓	✗
CAT II/III	✗	✗	✓ expected	✗

GPS, SBAS, GBAS… What we have today (cont.)

Technology that CAN be used by Airlines TODAY:

- GPS
  - Basic Navigation, RNP0.11 (best case) with INS integration
- SBAS
  - Provide RNP support up to RNP 0.1, INS not required
  - Provide LPV approaches up to CAT-I equivalent
- GBAS
  - Provide GLS approaches up to CAT-I equivalent today
    CAT-II/III is being worked and is expected around 2017
- GLONASS
  - Similar to GPS, can be augmented by SBAS (SDCM) and GBAS CAT-I
  - Certification basis developed by Russia;
    can certify GLONASS as a NON-TSO function in North America.
  - Mandated for installation in Russian registered aircraft,
    but not explicit on how/when to use GLONASS in flight.

Today's technology appears to satisfy most airline business needs

GPS, SBAS, GBAS… Equipage Status Today

- **GPS, SBAS, and GBAS Deployment on Airliners**
  - **GPS installed in most commercial passenger aircraft.**
    Factor for change: better (more efficient) airspace use, safety,
    the de-facto world GNSS standard today.
  - **SBAS not accepted by air transport in general, LP/LPV even less so.**
    Resistance to equip with SBAS continues.
    Factors for change: ADS-B compliance, no new ILS deployments & aging ILS replaced with LPV approaches, more stringent Missed Approach requirements, better RNP routes and airspace, WGS-84 height source (EGPWS & TAWS), safety, on its way to becoming a de-facto GNSS CAT-I world standard.
  - **GBAS not asked for by commercial air transport in general. ILS heavily used.**
    Factors for change: approved certification basis as CAT-II/III solution & Government acquisition of ground stations, aging ILSs replaced with GBAS,
    GBAS as a possible CAT-I solution where SBAS LPV coverage not provided (until SBAS catches up with coverage),
    not a de-facto CAT-I/II/III world standard until a major GBAS deployment happens.
  - **GLONASS**
    Factor: mandates imposed on Russian registered aircraft in Russia only,
    not a de-facto world standard, appears confined to Russia.

Brief Overview of Today's Technology

- GPS
  - Lots of SA-ON hardware still flying.
  - SA-OFF recently introduced
  - Issues:
    - lacks sufficient INTEGRITY (high traffic ADS-B?, RNP?), supplemented with integrated IRS solution (expensive)
    - will not support precision approach unless augmented
  - Positive: stable and proven operation over decades

- SBAS
  - is a GPS augmentation, capability to support GNSS
  - provides INTEGRITY (Primary Mission) and DIFFERENTIAL CORRECTIONS (for LP & LPV)
  - superb accuracy & integrity in entire coverage area
  - supports CAT-I precision approaches WITHOUT any reliance on airport infrastructure investments – it's all in the avionics
  - not expected to support CAT-II/III ever (even with L1+L5)

Single frequency 'GPS L1'

Brief Overview of Today's Technology (cont.)

- **GBAS**
  - **Is a GPS augmentation system but unlike SBAS, requires the use of a VHF Data Broadcast (VDB) uplink signal from ground station to avionics.**
  - **VDB signal occupies localizer band (108-118 MHz). Issues:**
    - **What antenna will be used as a VDB antenna?**
    - **VDB avionics system performance considered to be very stringent**
  - **Very, very few GBAS ground stations, unlikely to change.**
  - **Currently, GBAS certification supports CAT-I ONLY**
  - **Work underway to support GBAS CAT-II/III; Issue is insufficient INTEGRITY (ionosphere refuses to cooperate…).**

GPS L1 and VDB

GBAS CAT-II/III Certification with L1 only will be done with 9X% availability, the "X" is TBD…

Commercial Aviation Future Business Needs

- **Must fly and save/make money:**
  Cost side:
  - Lower cost of equipment acquisition & ownership
  - Lower training costs
  - A global “all-in” GPS receiver (GPS/SBAS/GBAS/etc…)
  - Better and more efficient routes/air space, reduce fuel cost
  - Guaranteed time of departure and arrival – meet schedule & reduce delays, costs of delays

This could be alleviated with today’s technology

  - **What new costs are coming:**
    - Mandates can impact business & force an artificial business case: No mandated equipage = No authorisation to fly
      Impact:
      - Forced equipage to meet mandate
      - Marginal (cost) performance improvement

Current and Future Mandates

- Current Mandate: GLONASS
  - Russian Government requires use of GLONASS for Russian registered aircraft.
  - SDCM is the Russian equivalent of WAAS, supports GPS, GLONASS, in future GALILEO
  - Mandate unclear concerning GLONASS use in flight deck

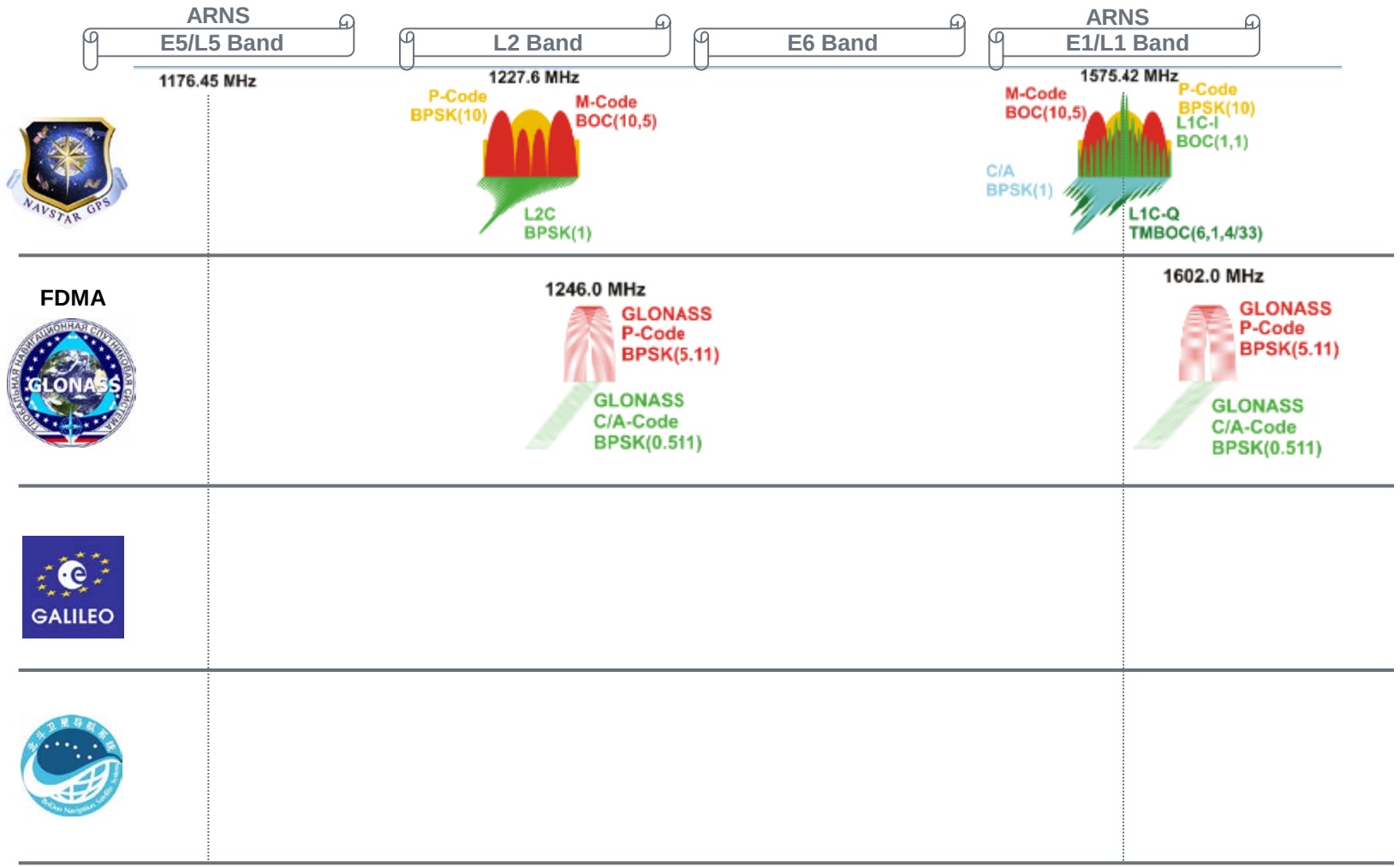
- Possible fallout mandates for GNSS equipage
  - GALILEO mandate in Europe?
  - BEIDOU-2 mandate in China?
  - Other nation states?
  - Concerns:
    - Liability, who pays in case of incident?
    - Enforcement, when/how to use in the flight deck?
    - Certification? Standards (ICAO?)? Processes?
    - Cost? Real & tangible benefits?

Future GNSS and Their Signals

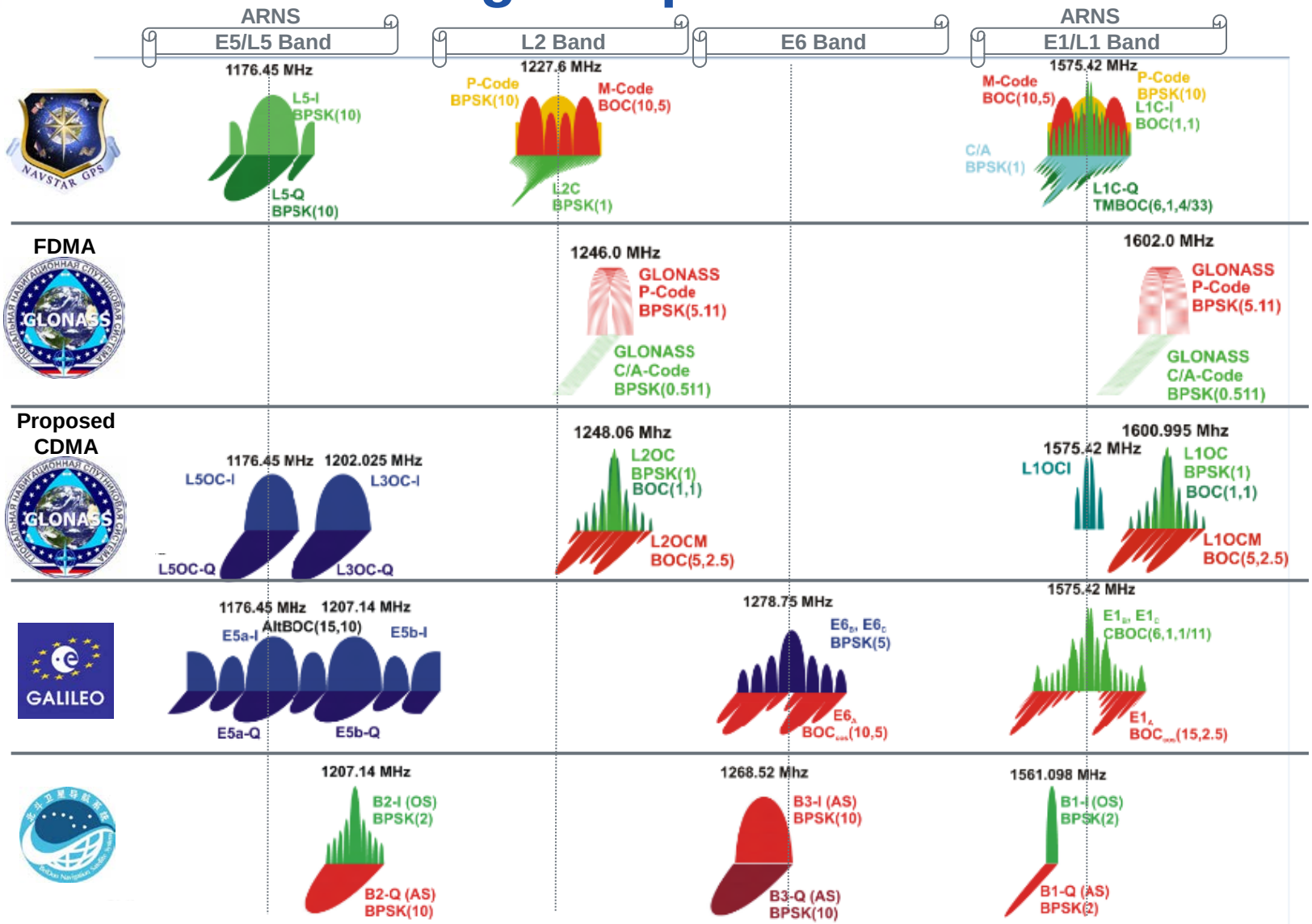
- Compatibility among new GNSS (with as GPS baseline)

	GPS	SBAS	GALILEO	GLONASS	BEIDOU-2
Dual Freq 'L1 – L5'	✓	✓	✓	?	✗
Dual Freq 'NEAR L1 – L5'	✗	✗	✗	✗	✓
FDMA	✗	✗	✗	✓	✗

Today's GNSS Signal Spectrum



Future GNSS Signal Spectrum



Future GNSS Receivers

Benefits of

	GPS	SBAS	GALILEO	GLONASS	BEIDOU-2
Dual Freq 'L1 – L5'	✓	✓	✓	?	✗
Dual Freq 'NEAR L1 – L5'	✗	✗	✗	✗	✓
FDMA	✗	✗	✗	✓	✗

Dual Frequency Receivers:

Measure and eliminate ionospheric induced errors

- **Fewer SBAS remote integrity monitor stations (RIMS) needed (since ionospheric induced errors can be measured by dual frequency receivers, do not need to monitor/model ionosphere).**
- **INTEGRITY improvement: CAT-I performance world wide with significantly reduced number of RIMS because ionosphere ceases to be a problem.**
- **GBAS CAT II/III performance and INTEGRITY is ASSURED because ionosphere ceases to be a problem.**

Dual Frequency receivers can provide a significant improvement in air transport capability and lower national infrastructure cost

Future GNSS Receivers (cont.)

	GPS	SBAS	GALILEO	GLONASS	BEIDOU-2
Dual Freq 'L1 – L5'	✓	✓	✓	?	✗
Dual Freq 'NEAR L1 – L5'	✗	✗	✗	✗	✓
FDMA	✗	✗	✗	✓	✗

Issues concerning

Dual Frequency Receivers:

Too many frequency bands

- Situation: L1 + L5 + FDMA exist today. Antennas: one L1 + L5 antenna, one FDMA antenna. Combined wideband and meet aviation RFI requirements not possible – cross-band RF pollution is very likely.
- Single antennas for L1 + L5 and "near" L1 + "near" L5 and FDMA are UNLIKELY due to interference requirements.
- "Near" L1 & L5 are too many bands for benefit to Commercial Aviation.
- Multi-antenna aircraft installation is a problem, issues: placement, EMI, radiation patterns, etc… STCs may become challenged.

One L1+L5 dual frequency band recommended. Encourage a L1 + L5 standard. If we Coexist with legacy FDMA then 2 antennas likely.

Future GNSS Receivers (cont.)

	GPS	SBAS	GALILEO	GLONASS	BEIDOU-2
Dual Freq 'L1 – L5'	✓	✓	✓	?	✗
Dual Freq 'NEAR L1 – L5'	✗	✗	✗	✗	✓
FDMA	✗	✗	✗	✓	✗

Benefits of

Multi-Constellation Receivers:

More measurements, constellation independence

- Fallback modes – when one constellation fails, another awaits.
- National independence for each state with its own GNSS
- Possible INTEGRITY improvement . Not clear if ultimately beneficial in the flight deck.
- Possibly improved spoofing resilience.
- Satisfy future mandate requirements.

Constellation and national GNSS independence can be strong drivers behind mandates.

Future GNSS Receivers (cont.)

Issues concerning

	GPS	SBAS	GALILEO	GLONASS	BEIDOU-2
Dual Freq 'L1 – L5'	✓	✓	✓	?	✗
Dual Freq 'NEAR L1 – L5'	✗	✗	✗	✗	✓
FDMA	✗	✗	✗	✓	✗

Multi-Constellation Receivers:

Complex. Expensive. Potentially many antennas.

- International standards development (ICAO?) meeting place is essential.
- Certification treaties highly recommended => recognition of one state's certification by another.
- No international agreement on how to protect navigation bands and deal with jammers and spoofers (law-making).
- The rules: when & where to use what GNSS and how.

Cost. Complexity. Certification. Mandates.
Lots of questions, no answers.

MCMF Receivers - The Future Today

Standards, Certification, Timelines.

- RTCA: L1 + L5 Antenna MOPS work underway, completion: 2015/6?
- NO L1 + L5 GNSS Receiver MOPS development work at all.
- Eurocae working Dual Frequency GALILEO MOPS. Final MOPS 2019?
- US has treaty in place with EC for GALILEO MOPS.
  Timelines for (L1 + L5) GPS/SBAS + GALILEO standards development do not have firm schedules. No certification basis exists at this time.
- Russian standards: available for GLONASS from Russian certification office and from ICAO. Available now, but certification process?
- BEIDOU-2 is UNKNOWN, but it is coming > 2020.
- While we suspect mandates may happen, no idea when they will happen.
- ICAO: a possible meeting place for world standards.

GNSS Receiver Technology and Complexity

- GPS,GALILEO,SBAS L1 front end
- GPS,GALILEO,SBAS L5 front end
- FDMA (GLONASS) front end
- Beidou-2 near L1 + near L5?
- Others?

-Multi-signal processing
-Multi-solutions & RAIM
-Multi-fallback modes

Highly complex processing
Requires significant computations compared to GPS/SBAS/GBAS L1-only Certified receivers

Jamming and spoofing detection with crew alerting ★

★ Assuming procedures in place to seek out jammers and spoofers

MCMF Receivers will be complex which will drive cost

MOPS & ICDs

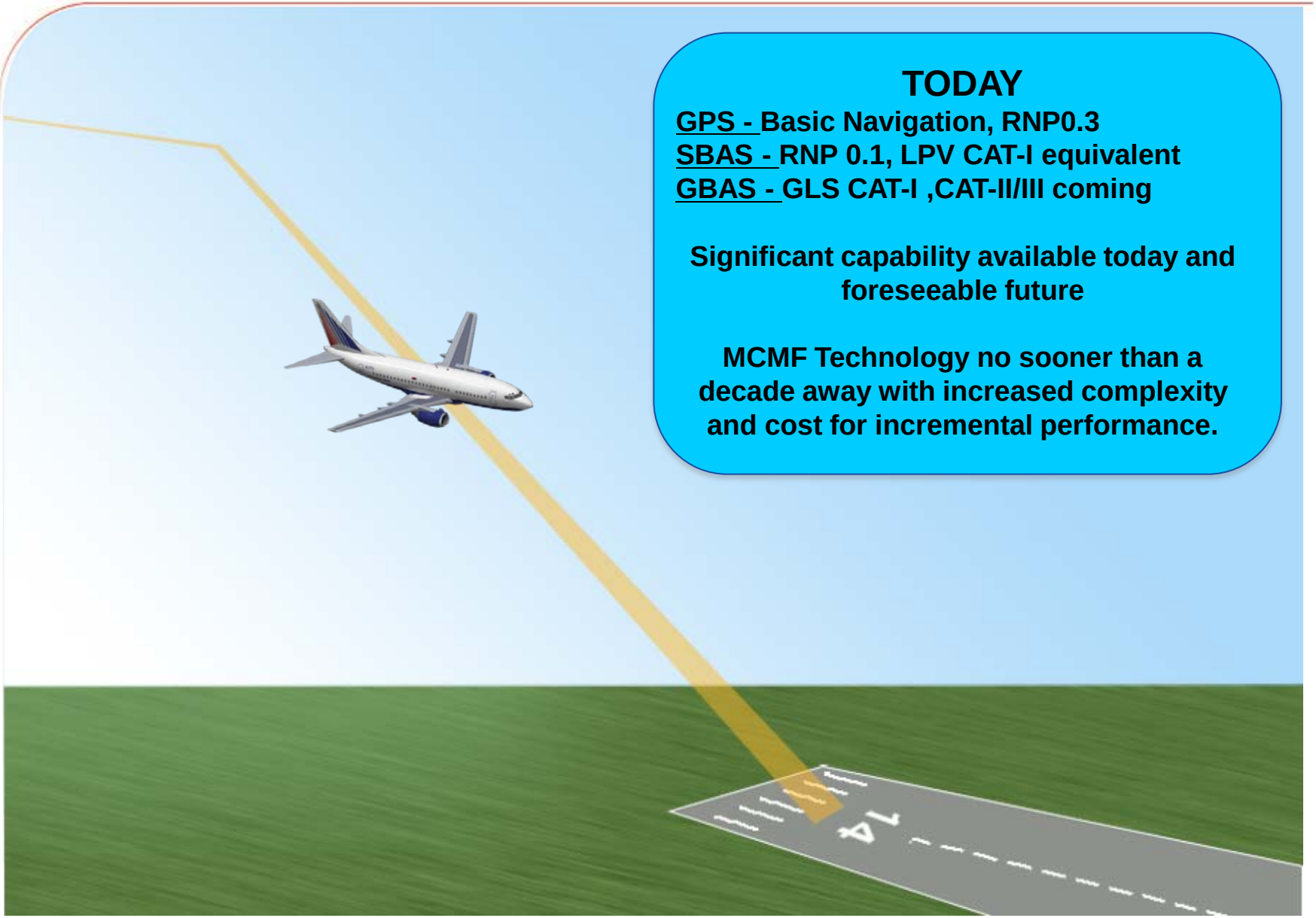
- Aviation receiver manufacturers require design guideline documents

	MOPS	ICD
GPS & SBAS L1 + L5	Non Existent ✗	GPS L1+L5 ICD stable, ✓ no SBAS L5 ICD ✗
GALILEO	In development ?	Appears to be stable ✓
GLONASS	MOPS exist ✓	Stable ✓
BEIDOU-2	Non Existent ✗	May Change ✗

Most Standards are not ready for MCMF Receivers

Closing Remarks

- Current single frequency L1 GPS/SBAS/GBAS not fully exploited by aviation. Hesitation in adopting current technology colors any business MCMF development negatively – result: manufacturers' investment into MCMF development questionable.
- Current single frequency L1 GPS/SBAS/GBAS receivers provide considerable navigation & approach capability that can be used to reduce operating costs and expand business. SBAS expanding world wide (GAGAN, SDCM, Others?). GBAS not deployed widely yet.
- Safety-of-Life certified MCMF technology will not become available any time soon (expect well beyond 2020…). Lots of work to do & uncertain investment case.
- GNSS mandates & pseudo-mandates (ILS decommissioning) should be expected.
- It might be prudent to fully exploit existing technology asap and much later with MCMF equipage as technology evolves. Being equipped with the current technology locks in the current equipage as the de-facto standard, lack of equipage exposes the industry to mandates for new equipage – food for thought.
- CMC has GPS/SBAS-LPV/GBAS-GLS technology to serve Commercial Aviation. CMC is committed to aviation and will have MCMF certified aviation receivers. CMC is very active in standards committees and will roll-out high performance/high quality aviation GNSS receivers as the industry evolves.


TODAY
GPS - Basic Navigation, RNP0.3
SBAS - RNP 0.1, LPV CAT-I equivalent
GBAS - GLS CAT-I ,CAT-II/III coming
Significant capability available today and foreseeable future
MCMF Technology no sooner than a decade away with increased complexity and cost for incremental performance.