International Civil Aviation Organization

Twenty Fourth Meeting of the Communications/ Navigation and Surveillance Sub-group (CNS SG/24) of APANPIRG

Web-conference, 30 November – 4 December 2020

Agenda Item 4: Aeronautical Mobile Communications Service and Aeronautical electromagnetic spectrum utilization

4.5 Other issues related to aeronautical communications service and aeronautical radio spectrum management

SPACE-BASED VHF COMMUNICATIONS IN 117.975-137 MHZ FREQUENCY BAND

(Presented by Singapore)

SUMMARY

The space-based VHF concept was first endorsed in 2018 by the ICAO Asia/Pacific Air Navigation Planning and Implementation Regional Group (APANPIRG) and supported by ICAO Communications Panel and Frequency Spectrum Management Panel. Singapore has since embarked on design studies with various industry partners and interested States.

With the support from ICAO and the different Regional Groups of the ITU, the space-based VHF frequency allocation (under AI 10 of World Radiocommunication Conference 2019 (WRC-19)) was formally accepted as an agenda item for WRC 2023 (WRC-23).

This paper aims to update the meeting on the preliminary technical study findings till date, and the progress of space-based VHF discussions at ICAO and ITU meetings.

1. INTRODUCTION

1.1 Space-based VHF communication is a concept in which aircraft operating in remote continental regions and oceanic areas could communicate with air traffic control (ATC) via VHF relayed through satellite(s). This concept, when implemented, is expected to be a parallel and complementary system to space-based automatic dependent surveillance-broadcast (ADS-B).

1.2 While VHF direct controller-pilot communication (DCPC) with aircraft operating in remote continental areas or oceanic regions is not possible, there are other communications available that are dependent on aircraft equipage. These systems range from HF communications to controller pilot data link communications (CPDLC). However, these systems are not recognised in the context of VHF direct controller-pilot communications (DCPC) that are required for ATC to provide reduced separation minima in remote airspace in a similar fashion as to what is provided in dense airspace in areas where terrestrial VHF communications infrastructure is predominant. Therefore, this leads to constraints in airspace capacity and efficiency in oceanic and remote continental areas, where VHF terrestrial infrastructure to provide DCPC communication operations with ATC is either not practical or not cost effective.

1.3 Figure 1 is an illustration of the space-based VHF communication concept. The space segment is able to receive from and transmit to standard VHF radios already installed on aircraft, and is designed to behave as if it was just another VHF-station located in the sky, with usually a larger footprint than terrestrial stations.

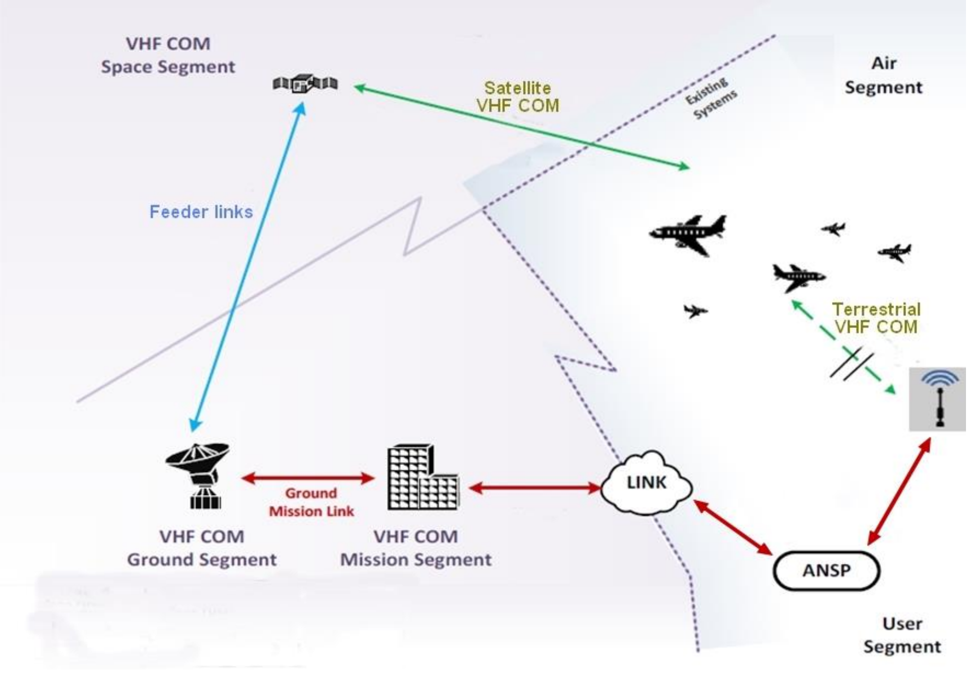

Figure 1 : the space-based VHF communication concept

1.4 Amendments to the ITU Radio Regulations ("RR") are necessary as the space-based VHF will require the ITU to harmonise and allocate the VHF frequency spectrum for aeronautical mobile-satellite (R) service (AMS(R)S) between satellite and aircraft. This approach is similar to the spectrum allocation to space-based ADS-B at the ITU WRC-15. With the support from ICAO (including 2018 APANPIRG) and the different Regional Groups of the ITU, the space-based VHF frequency allocation (under AI 10 of WRC-19) was formally accepted as an agenda item for WRC-23 Agenda Item 1.7, with approved resolution shown in the box below, where the approval of such frequency allocation will be discussed and sought.

*to consider a new aeronautical mobile-satellite (R) service (AMS(R)S) allocation in accordance with Resolution **428 (WRC-19)** for both the Earth-to-space and space-to-Earth directions of aeronautical VHF communications in all or part of the frequency band 117.975-137 MHz, while preventing any undue constraints on existing VHF systems operating in the AM(R)S, the ARNS, and in adjacent frequency bands*

1.5 Works on space-based VHF spectrum and technology studies have commenced and are progressing at various ITU and ICAO fora, namely:

a. ITU Working Party 5B (WP 5B) – reviewing the space-based VHF frequency allocation in accordance to ITU-R resolution 428 (WRC-19) for WRC-23, as stated above;

b. ITU Asia Pacific Telecommunity (APT) Preparatory Group (APG) – drafting/submitting APT's positions/support for WRC-23 Agenda Items;

c. ICAO Communications Panel – reviewing the ICAO Annex 10 SARPs to enable the future global adoption of space-based VHF services; and

d. ICAO Frequency Spectrum Management Panel (FSMP) – drafting/submitting ICAO's positions/support for aviation-related WRC-23 Agenda Items.

2. PRELIMINARY STUDY FINDINGS

2.1 High-Level Design Objectives

2.1.1 The following objectives and characteristics were proposed for the space-based VHF system under study by Singapore in partnership with Thales Alenia Space:

- The service provided is primarily voice ATC, as voice is the most critical VHF communication application in terms of safety and dependability
- No change is required on:
    - o aircraft avionic equipment, RF antenna setup and applicable specifications.
    - o terrestrial base stations specifications, and configuration of base stations located in FIRs which don't make use of the space-based VHF service
- No or minimal change would be required on:
    - o operational aspects for pilots and controllers
    - o terrestrial base stations configuration in FIRs with space-based VHF service
- Optimise the VHF coverage via use of spot beams

2.1.2 The service area covered by the satellite system will depend on its architecture and design. It can be regional, limited to one or several FIRs, or global. The satellite system is primarily intended to cover oceanic and remote continental areas where terrestrial service is not practical or not cost effective, but it could also be used to backup terrestrial stations in case they are affected by a catastrophic event.

2.2 Aircraft VHF receiver characteristics

2.2.1 <u>Aircraft VHF receiver antenna</u> Aircraft are usually equipped with two or three VHF antennas, in which case at least one of them is located on top of the aircraft, and one on the bottom. An example is given in Figure 2.

Figure 2 : example of VHF antenna placement on aircraft

2.2.2 The aircraft VHF receiving antenna pattern is an essential element to be considered in the studies. The performances of available products show that:

- Relatively low gains are achieved, typically 3 to 5 dBi maximum
- Radiation patterns are globally omni-directional, and more precisely
    - Omni-directional in azimuth
    - Co-sinusoidal in elevation, meaning a theoretical zero is achieved at aircraft zenith (90° elevation)

2.2.3 Based on similar past ITU-R studies on aeronautical VHF communications, the aircraft antenna pattern in Figure 3 has been considered. It can be noted that the co-sinusoidal shape and consequential null at aircraft zenith has important implications on the performance of the satellite VHF link.

2.2.4 In addition, aircraft surfaces (tail, body, wings) are not taken into account in such a theoretical radiation pattern. Actual implementation may lead to alteration of the pattern.

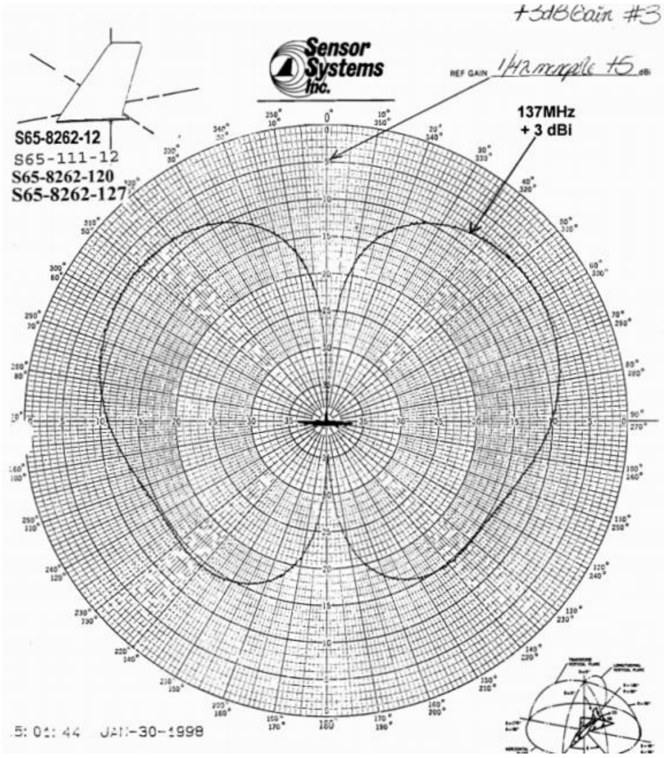

Figure 3 : Typical aircraft VHF antenna pattern – vertical cut
(without aircraft body)

2.2.5 Aircraft VHF receiver performance requirement Regarding aircraft VHF receiver sensitivity, ICAO SARPs provide the following reference recommendation in Annex 10 Volume III (Communication System) Part II (Voice Communication Systems) of the Convention on International Civil Aviation:

Part II ***Annex 10 — Aeronautical Communications***

2.3 SYSTEM CHARACTERISTICS OF THE AIRBORNE INSTALLATION

[…]

2.3.2 Receiving function

[…]

2.3.2.2 SENSITIVITY

2.3.2.2.1 **Recommendation.—** *After due allowance has been made for aircraft feeder mismatch, attenuation loss and antenna polar diagram variation, the sensitivity of the receiving function should be such as to provide on a high percentage of occasions an audio output signal with a wanted/unwanted ratio of 15 dB, with a 50 per cent amplitude modulated (A3E) radio signal having a field strength of 75 microvolts per metre (minus 109 dBW/m2).*

Note.—For planning extended range VHF facilities, an airborne receiving function sensitivity of 30 microvolts per metre may be assumed.

2.2.6 A satellite system relaying aeronautical VHF communications over oceanic and remote continental areas can be considered as part of "extended range VHF facilities", hence the underlined

Note referring to a **field strength of 30 microvolts per metre** would be more relevant for the satellite case than the 75 microvolts per metre reference. Such a field strength corresponds to a **sensitivity power flux of -116.2 dBW/m².**

2.2.7 In addition, the required performance of actual aircraft VHF receiver can be found in available aeronautical industry standards. EUROCAE and RTCA have developed "Minimum operational Performance Specification (MOPS) for airborne VHF receiver-transmitter operating in the frequency range 117.975-137 MHz" (reference: EUROCAE ED 23C dated June 2009 and RTCA DO-186B dated November 2005).
These documents specify that:

- the output audio signal shall have an output Signal plus Noise plus Distortion over Noise plus Distortion (SINAD) of 6 dB.
- the minimal receiver sensitivity to achieve this target is **-93 dBm**.

2.2.8 Feeder/cable losses on board aircraft shall also be accounted for. It is usually estimated as 2 to3 dB (and confirmed in some ETSI reference), and it is therefore proposed to consider a worst case of **3 dB** in this study.

2.3 Operational Environment for the transmission and reception of satellite VHF

2.3.1 Satellite-aircraft range. The effective path range is relative to the satellite altitude, and to the actual satellite and aircraft positions, which change continuously. Definition of the maximum range considered for satellite operation is helpful in the assessment of system performance, and is an important assumption in the overall architecture design. Together with the targeted service area (FIR specific, regional, global) and the desired availability performance under given propagation conditions, this parameter directly impacts the number of satellites required in the satellite constellation. At this stage, it is proposed to consider a **maximum 1000 km (540 nm) range** for the reference link budget.

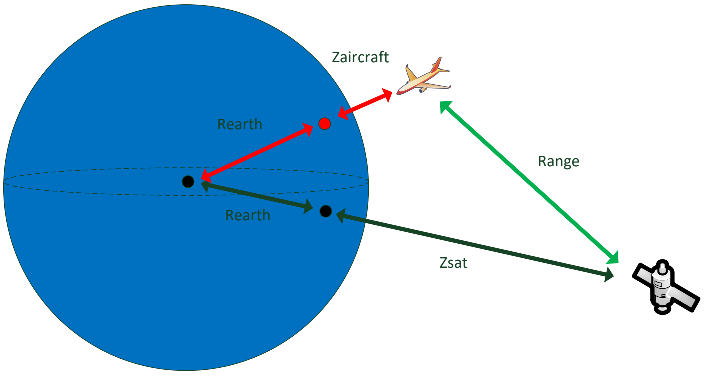

Figure 4 : satellite-aircraft range

2.3.2 Propagation. Satellite transmissions in VHF are known to be significantly affected by scintillation events that occur within the ionospheric layer. The ionosphere causes a delay proportional to the electron-density along the wave path, where the wave path passes patches of more or less dense ionosphere, scintillation occurs.

Scintillation is generally more pronounced at high latitudes (e.g. polar and auroral zones) and within $\pm 20°$ of the geomagnetic equator. For much of the locations in mid-latitudes, propagation loss and phase changes due to scintillation will be less pronounced than those at high latitudes or near the geomagnetic equator. At this stage according to Recommendation ITU-R P.531-14, it is recommended that Global Ionospheric Scintillation Model (GISM) be used to predict the effects of scintillation on a given link geometry. Careful consideration of the temporal, spatial and geomagnetic environment must be used to assess the range of ionospheric behaviour, noting that scintillation events last from 30 minutes to hours and commence after local ionospheric sunset.

Accurate predictions are still challenging for the design of telecom systems. Given the limit of the current model accuracy, it is not possible yet to precisely quantify ionospheric propagation losses in relation to a given link availability for all ranges of latitude and aircraft station elevation.

In worst cases, at equatorial areas, significant attenuations of much more than 10 dB could be expected in the extreme worst case (> 15 dB reported for 1.5 GHz, as indicated in Figure 5). The highest intensity are observed, for every longitudinal positions, for a period of time after sunset at 18:00 (local time) and up to 0:00 at the equinox period, and for years of maximal solar activity.

Further work is required in order to appropriately take ionospheric losses into account in the design of an aeronautical VHF satellite system. States/Administrations who have prior experiences on such technical studies are encouraged to share data on scintillation effects on satellite systems. At this stage, it is proposed to take into account the three following reference ionospheric losses:

- A low level of 3 dB attenuation losses for medium latitude regions.
- A medium level of 5 dB attenuation losses for high latitude regions (this medium case is retained in the reference link budget).
- A high level of **10 dB attenuation losses** for low latitude regions.

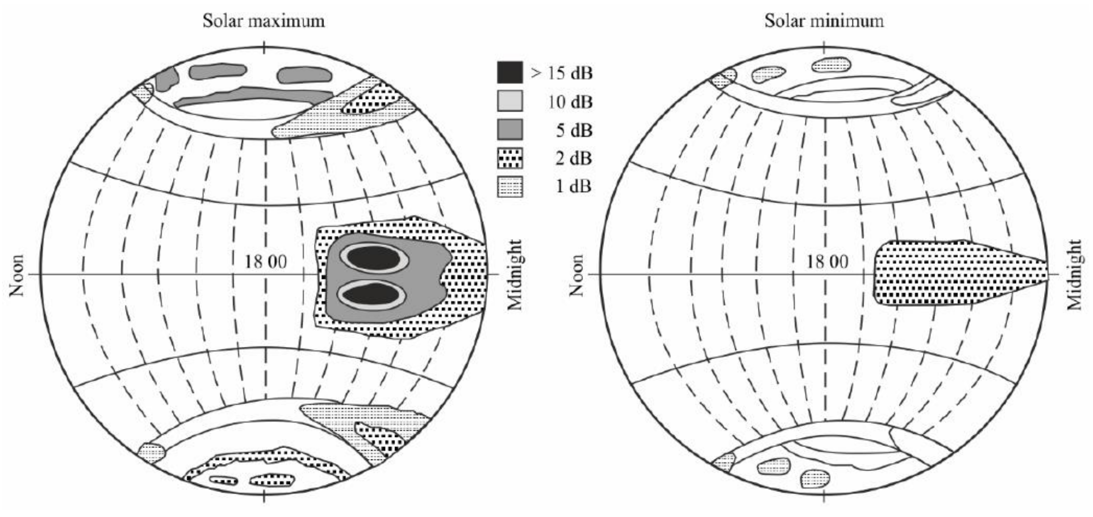

Figure 5 : Ionospheric propagation loss at 1.5 GHz during solar maximum and minimum years (from Recommendation ITU-R P.531-14)

2.3.3 Polarization. Emissions of standardised air-ground VHF communication systems are vertically polarized. For systems that use linearly polarized antennas, potential phase rotation through the ionosphere depends on many factors such as location, time of year, time of day, solar cycle and geomagnetic conditions, hence it is very difficult to predict the extent of associated polarization loss.

At satellite level, a setup with linear polarization, compatible with the vertical polarization used at aircraft would be preferable for link budget purposes. However, its design seems difficult to match in terms of alignment with aircraft antenna, taking into account the real-time link geometry between the transmitter and receiver, and Faraday rotation changing polarization angles. For this reason, **circularly-**

polarized receiving and transmitting antennas are assumed, mitigating by design against the Faraday effect, and leading to a **polarization loss factor of at least 3 dB**.

2.4 Satellite Transmitter Characteristics

2.4.1 The output of the link budget considered for satellite downlink will be the power required on-board the satellite. This power is another important driver of satellite system design, which cannot exceed a few hundred watts maximum to remain implementable. It will determine the size and class of satellite that can be considered for an aeronautical VHF satellite system dimensioned for the given satellite-aircraft range of 1000 km.

2.4.2 Regarding the gain of the circularly polarized satellite transmitting antenna, a value of 3 dB is considered. Depending on antenna technology, design, number of combined antennas, etc, the typical gain of satellite VHF antenna could range between 0 dB and 6 dB. The proposed value of 3 dB is therefore considered as a realistic intermediate case.

2.4.3 Preliminary downlink link budget is shown below for reference.

Satellite-to-Aircraft Transmission	**Units**	**Value**
Frequency	MHz	137
Range	km	1000
Transmitter		
RF Power	**W**	**330**
Tx Antenna Gain	dB	3
Feeder losses	dB	1
EIRP	dBW	27.2
Signal propagation		
Free space losses	dB	135,2
Additional propagation losses (scintillation)	dB	5
Polar losses to receive V polar	dB	3
Effective received power flux at antenna	dBW/m^2	-111.8
Recommended SARPs power-flux for extended range terrestrial transmissions	dBW/m^2	-116.2
SARPs power-flux margin (extended range)	dB	4.4
Receiver		
Rx Antenna Gain	dB	-4
Rx feeder losses	dB	3
Rx signal	dBm	-93,0
Rx sensitivity (target SINAD: 6dB)	dBm	-93,0
Receiver Link Margin	**dB**	**0**

3. STATUS UPDATES & NEXT STEPS OF SPACE-BASED VHF

3.1 Technical Feasibility Studies - CAAS and its industry partners will continue with the technical studies, with the primary focus on the design of the satellite constellation, coverage optimisation and other technical parameters (e.g. the VHF radios and antennae), as shown in Section 2 of this paper. The Proof-of-Concept (POC) trials and verification tests may take place following the completion of all the technical studies. *For such trials/tests, coordination will be made with the ICAO Asia Pacific Regional Office and other regional offices, if required, for the required frequencies*.

3.2 Frequency Compatibility Studies – The relevant technical study findings to support the ITU-R study analysis work required in accordance with Resolution 428 (WRC-19) as defined in WRC-23 Agenda Item 1.7, are being discussed at APG and WP 5B meetings. *France and Singapore commenced the frequency compatibility studies work and submitted an Input Document at the 2020 Nov ITU Working Party 5B (WP 5B) meeting to update on Agenda Item 1.7*. In parallel, CAAS is also working closely with interested States and ICAO FSMP to develop methods to satisfy this agenda item, in the current WRC cycle leading up to WRC-23.

3.3 Draft ICAO Position for WRC-23 Agenda Item 1.7 – FSMP is also drafting ICAO Positions for WRC-23, in addition to coordinating the frequency compatibility studies work required for WRC-23. The current draft ICAO Position for WRC-23 Agenda Item 1.7, as agreed at the 2020 Aug FSMP Working Group 10 meeting, is as follows:

> *To support ITU-R studies and the definition of relevant technical characteristics as called for by Resolution 428 (WRC-19).*
>
> *To support a global allocation to the aeronautical mobile-satellite (route) service for both the Earth-to-space and space-to-Earth directions in the frequency band 117.975 – 137 MHz and that the use of the allocation be limited to the relaying of aeronautical VHF air traffic management communications.*
>
> *To support that those systems shall operate in accordance with international standards and recommended practices and procedures established in accordance with the Convention on International Civil Aviation.*
>
> *To ensure that any change to the regulatory provisions and spectrum allocation resulting from this agenda item do not adversely impact the operation of existing VHF systems in the band 117.975 – 137 MHz operating in the AM(R)S, including regional usage of terrestrial VHF, nor require any changes to aircraft equipage or to existing installations.*

3.4 ICAO Communications Panel Data Communications Infrastructure Working Group (DCIWG) Space-based VHF Sub-Group to Review Annex 10 SARPs – *The ICAO DCIWG meeting in Oct 2020, approved the setup of a new project team* sub-group, either under Project Team – Satellite (PT-S) or Project Team – Technology (PT-T*), to review existing ICAO Annex 10 SARPs, and recommend if amendments are required in ICAO SARPs and relevant guidance materials to enable satellite-based VHF operations for AMS(R)S.* This Project Team is expected to table the proposed amendments to ICAO Communication Panel and its relevant Working Groups for endorsement/approval.

4. DRAFT CONCLUSION

4.1

<table>
<tr><td colspan="4">Draft Conclusion/Conclusion/Decision XX/XX - Space-based VHF communications There is a need to obtain approval at WRC-23 for frequency allocation of space-based VHF communications services, and for ICAO and States/Administrations in APAC region to support the frequency compatibility studies, planning/implementation of space-based VHF proof-of-concept/trials, and States/Administrations in APAC region to participate in review of ICAO Annex 10 SARPs for adoption of space-based VHF operations.</td></tr>
<tr><td colspan="3">What: Click here to enter text.
a) That, ICAO to coordinate and support, and States/Administrations in APAC Region to support, the frequency compatibility studies required for WRC-23 approval to allocate the current aeronautical VHF frequency band for space-based VHF operations.

b) That, ICAO and States/Administrations in APAC Region, support the planning and implementation of the space-based VHF proof-of-concept/trials following completion of technical feasibility studies, if required.

c) That, States/Administrations in APAC Region, participate in the ICAO DCIWG space-based VHF sub-group to review ICAO Annex 10 SARPs for adoption of space-based VHF operations.</td><td>Expected impact:
☒ Political / Global
☒ Inter-regional
☒ Economic
☐Environmental
☒ Ops/Technical</td></tr>
<tr><td colspan="2">Why: to support implementation of space-based VHF services</td><td colspan="2">Follow-up: ☒Required from States</td></tr>
<tr><td colspan="2">When: 2-Jan-21</td><td colspan="2">Status: Draft to be adopted by PIRG</td></tr>
<tr><td colspan="4">Who: ☒Sub groups ☒APAC States ☒ICAO APAC RO ☒ICAO HQ ☐Other:</td></tr>
</table>

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) Note the above information;

b) Invite States to comment or provide inputs, if any, on the technical information described in Section 2 above;

c) Invite interested States to work with CAAS on the technical and frequency compatibility studies on space-based VHF; and

d) Review the above draft conclusion.

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