An alternate approach to lunar human exploration: The Flexible Lunar Architecture for Exploration (FLARE).

M. E. Evans[1], L. D. Graham[1], [1]NASA Johnson Space Center (JSC) Astromaterials Research and Exploration Science (ARES), michael.e.evans@nasa.gov

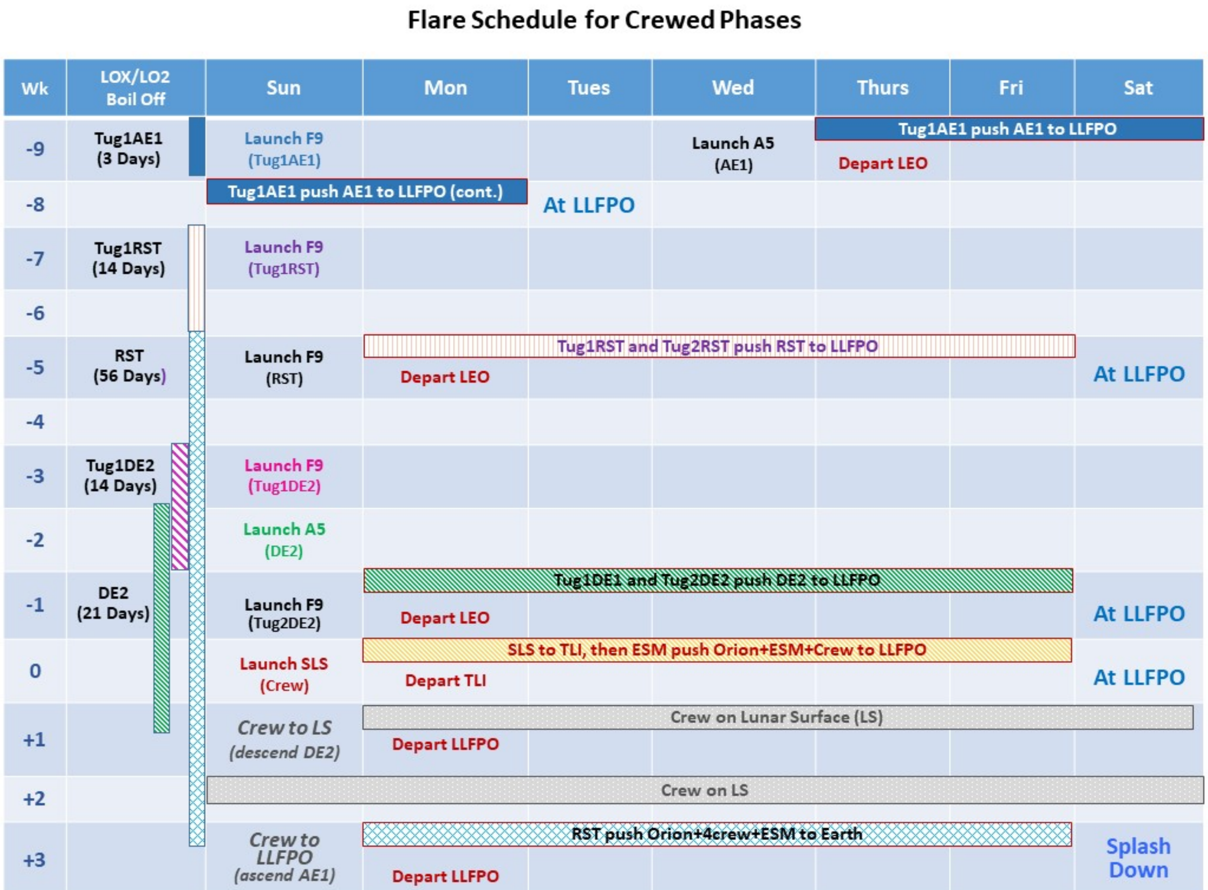

Figure 1: Possible launch schedule for FLARE human lunar mission

Introduction: The Flexible Lunar Architecture for Exploration (FLARE) is a practical methodology to deliver four crew to the lunar surface for 7-14 days then safely return them to Earth. FLARE can be implemented whenever the component vehicles are ready for launch. Detailed calculations and analysis for FLARE has been published in a scientific journal [1] and as a NASA Technical Memorandum (TM) [2].

FLARE requires a minimum sequence of 8 launches in a 9-week period: 5 on SpaceX's Falcon 9 (F9), 2 on United Launch Alliance's (ULA) Atlas 5 (A5), and 1 on NASA's Space Launch System (SLS) Block 1 (see Figure 1). The lunar orbit is a circular Low Lunar Frozen Polar Orbit (LLFPO) at an altitude of 100 km and inclination of 86.5° overflying near the South Pole every 2 hours. Extra launches could deliver Gateway components to LLFPO, and lunar surface infrastructure assets to extend the surface mission from 7 to 14 days.

FLARE was developed as an alternative to NASA's Human Landing System (HLS) reference architecture from the Design Analysis Cycle (DAC) #2 [3]. The DAC2 baselined the use of SLS, Orion and the European Service Module (ESM) with an unspecified human lander for their architecture. They selected a highly elliptical Near-Rectilinear Halo Orbit (NRHO) for Orion due to documented propulsion limitations of the SLS Block 1 and ESM [4], which prevented use of a Low Lunar Orbit (LLO). Orion in this NRHO overflies the near lunar South Pole once every 7 days at an altitude of 2750 km, which is undesirable for either surface science observation or mission safety (poor surface aborts) [1]. DAC2 mentioned a "Transfer Element" (TE) as an additional vehicle to move assets between NRHO and LLO. FLARE expands upon the TE concept by proposing use of a "SpaceTug" for mass transfer between Low Earth Orbit (LEO) and LLO [5].

Concept Details: FLARE is supported with technical analysis of multiple factors, such as mass and change in velocity (ΔV) calculations including crew, cargo, and propulsion systems. FLARE develops a plan for launch and mating of necessary components in LEO and LLFPO. FLARE provides a reference design for the SpaceTug and a human lander, including both the pressurized Ascent Element (AE) and a "common" Descent Element (DE) capable of delivering either crew or cargo to the lunar surface. Payload volumetric evaluations are considered within existing Commercial Launch Vehicle (CLV) fairings, and also for crew logistics on the lunar surface (within both the AE and in an optional habitation module). A lunar surface concept of operations is presented for Extra-Vehicular Activity (EVA) traverses and crewed exploration activities for a 7-14 day campaign. FLARE also provides an optional reference concept for an individual crew mobility device, called the "Lunar ATV" (LATV).

The required FLARE launch schedule requires a nine-week period that integrates launch pad availability with predicted boil-off rates for vehicle cryogenic propellants (Figure 1). *FLARE does not require the Gateway components of Power & Propulsion Element (PPE) [6] or the Habitation and Logistics Outpost (HALO) [7];* however, these elements are available as optional phases in FLARE with extra CLV launches.

Adding a single SpaceX Falcon Heavy (FH) to the required minimum sequence expands the lunar surface duration from 7 to 14 days. The FH lifts a cargo DE (which then executes the TLI and lunar descent) mated to a payload including an inflatable human habitat, LATVs, science experiments and a lunar In-Situ Resource Utilization (ISRU) technology demonstration.

The key to FLARE is the SpaceTug (based on an existing ULA "Common Centaur" upper-stage vehicle) launched on a CLV. SpaceTugs transfer assets, such as the human lander, between LEO and LLFPO. The SpaceTug uses cryogenic liquid oxygen (LOX) and hydrogen (LH_2) as propellants (prop), and uses ULA's Integrated Vehicle Fluids (IVF) technology (developed for the new ULA Advanced Cryogenic Evolved Stage (ACES)) [8]. The IVF re-pressurizes the prop system and provides power to the vehicle [9]. The boil-off of cryogenic LOX/LH_2 must be minimized in vehicles on-orbit. New technologies are available to reduce cryogenic boil-off [10, 11], and launch schedules were developed to ensure propellant volume sufficient to meet mission objectives with a boil-off rate of 0.5%/day.

FLARE uses a single SLS Block 1 to lift crew in the Orion+ESM to Trans-Lunar Injection (TLI), then the ESM provides the propulsion to insert the Orion+ESM in LLFPO. A "Return SpaceTug" (RST), delivered to LLFPO before the crew launches, provides the necessary prop for crew return to Earth in Orion+ESM.

Phases and Schedule: The general sequence is divided into five Phases A-E (with each subdivided into subphases a-b):

A. Deliver Gateway equipment to LLFPO (Optional)
B. Deliver lunar surface precursor equipment (Optional)
C. Deliver vehicles to LLFPO for crewed mission support (Required)
D. Deliver crew to LLFPO, then lunar surface, then to LLFPO (Required)
E. Return crew to Earth (Required)

The basic FLARE schedule is provided in Figure 1 (no optional phases). Note the FLARE sequence naming convention is XXY, where the XX identifies the vehicle element and Y is an incrementing counter for those vehicle elements. Lunar vehicle elements include the Ascent Element (AE) to lift the crew from the lunar surface to LLFPO, and the Descent Element (DE) for delivering crew from LLFPO to the lunar surface. For SpaceTugs, the naming convention is repeated, e.g. Tug1DE1 (which identifies the first SpaceTug that pushes the first Descent Element from LEO to LLFPO). Generic vehicle discussion uses their acronym only without a counter (Y). Launch vehicles for the required phases are the Atlas 5 (A5), the SpaceX Falcon 9 (F9) and the NASA SLS Block 1 (SLS).

Lunar Landers: FLARE provides a reference 2-stage human lander design concept, consistent in mass and volume with numerous previous lunar lander designs [12]. The components are a "Common" Descent Element (DE) for either cargo or crew delivery to the lunar surface from LLFPO, and a pressurized Ascent Element (AE) for crew transfer to and from the lunar surface. The AE provides a lunar surface residence for four crew up to seven days. The FLARE concept can accommodate any future commercial lander (developed for either humans or cargo) that falls within the mass, diameter, and height constraints of available CLVs launching elements to LEO.

References: [1] Evans ME & Graham LD (2020), *Acta Astronautica* 177, [2] Evans ME & Graham LD (2020), *NASA NTRS* TP-2020-220517, [3] NASA (2019) https://beta.sam.gov/opp/d5460a204ab23cc0035c088dcc580d17/view, [4] Whitley R and Martinez R (2016), *IEEE Aerospace Conference,* [5] Evans ME & Graham LD (2020) *LPSC* Abstract 2326, [6] Ticker RL et al (2019), *AIAA Propulsion and Energy Forum* 3811, [7] Foust, J (2019) https://spacenews.com/iss-partners-endorse-modified-gateway-plans/, [8] ULA (2019) https://www.ulalaunch.com/about/news/2019/08/14/snc-selects-ula-for-dream-chaser-spacecraft-launches [9] Barr (2015) *AIAA SPACE 2015 Conference,* [10] Gravlee (2012) *Cryogenics* 52, [11] Plachta (2016) *Cryogenics* 74, [12] Connolly JF (2019) *NASA NTRS* SP-2019-31985