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Boundary Layer Transition (BOLT) Flight Test Program

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30 November 2021
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Subject: Boundary Layer Transition (BOLT) Flight Experiment Final Report (Grant
FA9550-17-2-0001, period 1 September 2019 through 30 November 2021)

This report summarizes the four-year and three-month research effort by the Johns Hopkins University Applied Physics Laboratory (APL) under grant number FA9550-17-2-0001 from the Air Force Office of Scientific Research (AFOSR) to plan and conduct a hypersonic flight test experiment. APL led a collaborative team of Government, academia, and industry partners in the Boundary Layer Transition (BOLT) flight test experiment. Detailed technical activities are documented in annual reports from Years 1–4 of the grant as well as in supplemental deliverable reports that have been provided to AFOSR (Ground Test Final Report, Inspection Report, and Assembly Instructions report). The flight experiment campaign, originally planned for May 2020, was ultimately delayed due to the COVID-19 global pandemic. A no-cost extension of the present grant was given by AFOSR to extend the period of performance end date to 30 November 2021 to cover activities associated with the flight campaign that occurred in June 2021. This report will summarize the program execution from a schedule and financial standpoint and will provide a brief summary of the flight experiment. A status of all deliverables will also be provided. The APL post-flight research will continue on a separate grant from AFOSR (FA9550-20-1-0043).

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1. Introduction

The Boundary Layer Transition (BOLT) flight experiment was designed to study hypersonic boundary layer transition on a geometry with low-curvature concave surfaces and highly-swept leading edges. Significant research was conducted to understand transition mechanisms on the BOLT geometry in a widespread preflight ground testing and analysis campaign conducted by a broad team of organizations, culminating in the design and fabrication of a flight experiment to measure transition physics in flight [1–9]. A two-stage sounding rocket flight vehicle was to deliver the BOLT experiment payload to hypersonic flight conditions during both the ascent and descent of a ballistic trajectory. The BOLT experiment was instrumented with over 340 channels of scientific instrumentation intended to measure surface temperatures, heat transfer rates, and pressure fluctuations through the atmosphere to characterize boundary-layer transition behavior.

BOLT was led by the Johns Hopkins University Applied Physics Laboratory (APL) and is conducted by a diverse team of Government, industry, and academic organizations including the Air Force Research Laboratory Air Force Office of Scientific Research (AFRL/AFOSR) and Aerospace Systems Directorate (AFRL/RQ), German Aerospace Center (DLR) Mobile Rocket Base (MORABA) [10], Purdue University, the University of Minnesota, Texas A&M University, CUBRC, NASA Langley Research Center, GoHypersonic Inc., and VirtusAero LLC. Flight computers based on the HIFiRE design were provided for use on BOLT by the Australia Defence Science and Technology (DST) group. The test range operations occurred at the Swedish Space Corporation (SSC) Esrange Space Center in northern Sweden. Together, this multi-national team has advanced methodologies to understand transition mechanisms on the BOLT geometry. Extensive documentation of the pre-flight research performed by the team, as well as the design and fabrication of the BOLT flight experiment payload under the current AFOSR grant FA9550-17-2-0001 were provided in previous Year 1–4 annual reports as well as in a special section of the Journal of Spacecraft and Rockets [1–9].

The BOLT payload (or “Flight Geometry”) contained a scientific experiment designed with a unique shape provided by AFOSR for study in this program. Figure 1a shows the Flight Geometry outer mold line, the complex geometry that serves as the subject of the scientific research. Figure 1b shows the completed flight hardware including the Flight Geometry, as well as the TSM and PSM sections. Additional details of the experiment design are summarized in [2]. The Flight Geometry contained an extensive suite of surface instrumentation (thermocouples, pressure sensors, and heat transfer gauges) at 226 discrete locations providing a total of 344 scientific measurements.

Figure 2 shows the overall BOLT Flight Research Vehicle, with dimensions in millimeters. The image shows the 866 mm Flight Geometry along with the payload and transition support modules (PSM and TSM, respectively), the cold gas system (CGS) and attitude control system / service module (ACS/SM) which will reorient the vehicle ahead of reentry for the descent experiment, and the motor adapter (MA). The first stage consists of the S31 solid rocket booster from the Brazilian Aeronautics and Space Institute (IAE) of the Department of Aerospace Science and Technology (DCTA) and the second stage consists of an Improved Orion motor. The two stages were selected with the intent to deliver the BOLT Flight Geometry to conditions to make measurements within the hypersonic regime (Mach 5 to 7) for measurements of transition on both ascent and descent. Further details are provided in Hörschgen-Eggers et al. [4].

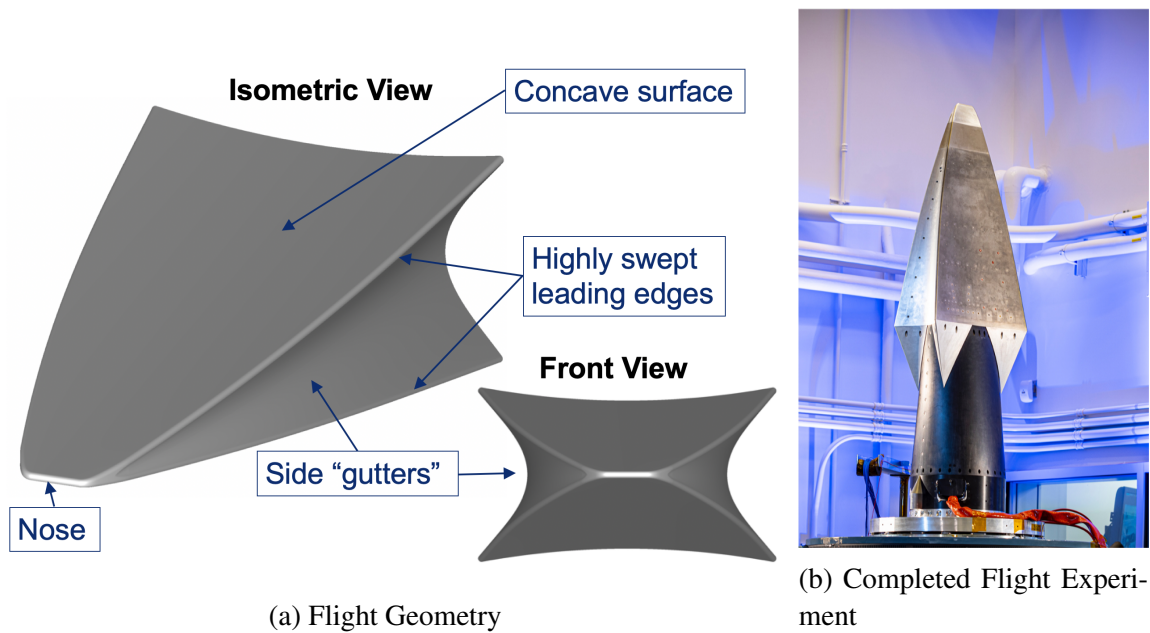


Figure 1. BOLT Flight Geometry

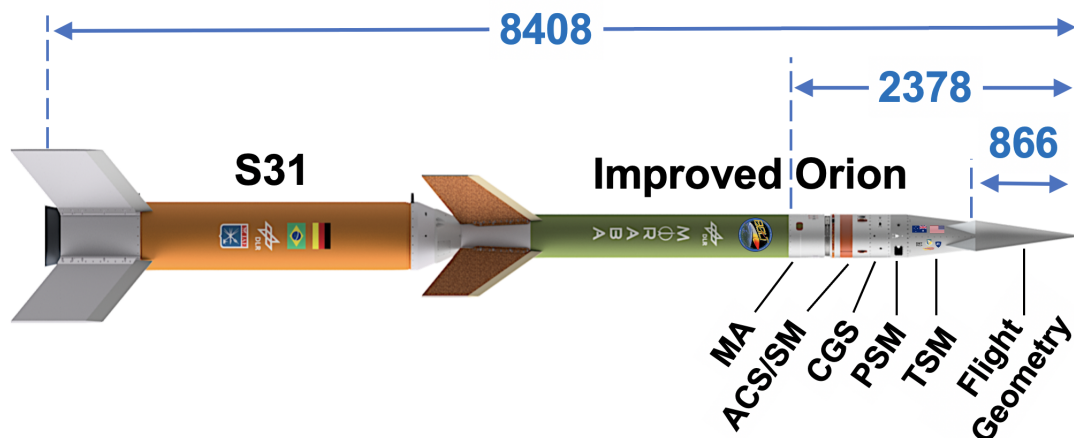


Figure 2. BOLT Flight Research Vehicle (dimensions in mm). Image provided by DLR MORABA.

A flight campaign was conducted to prepare and launch the vehicle and payload in June 2021 at Esrange Space Center near Kiruna, Sweden. Following a successful flight campaign, the launch of the vehicle occurred at 0250 CEST local time (0050 UTC) on 23 June 2021. Shortly after launch, the flight vehicle exhibited unexpected aerodynamic behavior by entering into a coning motion at relatively large angles of attack. The onset of the coning motion occurred near stage separation, after which the vehicle angle of attack increased. Due to increased drag from the coning motion and large angles of attack, the entry of the vehicle into the nominal trajectory was prohibited. The vehicle reached a maximum Mach number of approximately 3.9 during ascent versus the nominal 7.0. The majority of the ascent phase occurred with angles of attack from 10–30°. The vehicle reached an apogee of 78 km versus the nominal 267 km. The BOLT vehicle reentered the atmosphere at a relatively large angle of attack and preliminary data show that the angle of attack was gradually reduced as the vehicle descended. The BOLT flight experiment, still attached to the second stage motor, impacted at approximately 275 s after liftoff at a distance of 12 km downrange. This paper will focus on the scientific data from the as-flown trajectory, while several companion papers are planned that will focus on efforts to investigate the cause of the BOLT flight unexpected behavior.

While the BOLT experiment did not reach its intended Mach 5–7 conditions in flight, the experiment did gather potentially useful boundary-layer transition measurements at supersonic conditions (Mach 2–4), primarily during the descent phase of flight. This phase of flight will be the focus of the final paper. Reentry to the atmosphere occurred several minutes sooner than anticipated due to the much lower apogee, resulting in only one of the three scientific data telemetry streams being active during the descent phase. Thus, a limited number of instrument data on the order of 90 channels were received during the BOLT descent. This paper will present an analysis of boundary-layer transition inferred from the data from these sensors during the supersonic descent.

2. Program Execution and Final Schedule

This section provides an overview of program execution and final schedule from the APL grant kickoff on 1 September 2017 through the ultimate flight test on 23 June 2021 to the grant end date on 30 November 2021. Although a second grant funds APL to complete the remaining post flight investigation review, this program schedule describes the major activities that comprised the preflight analysis and testing as well as the execution of the flight campaign. An overview of the major activities and milestones by year appears in Figure 3, with the red cross marks denoting the flight campaign original, alternate, and final dates. The majority of the first year of the research was devoted to extensive computational fluid dynamics (CFD) modeling and ground testing. During that timeframe, design work for the flight experiment was also ongoing. The Flight Geometry Critical Design Review (CDR) was held approximately 18 months following grant kickoff, however fabrication of some components began ahead of the CDR such as the nosetip. The Flight Geometry was delivered to AFRL/RQ in November 2019 in anticipation of the nominal May 2020 flight campaign. Ultimately, the flight campaign was delayed until June 2021 due to the COVID-19 global pandemic.

The execution of the program was highly collaborative, featuring an extended team of over nine organizations and regular telecons that began as weekly for APL to provide the extensive team with

updates and to coordinate activities to meet the schedule ahead of the flight test. Table 1 attempts to summarize all of the major meetings, telecons, and the corresponding topics/decisions/outcomes during the program. Details of these discussions are included in regular status bullet updates from throughout the entire program execution that are provided for archiving in Appendix A.

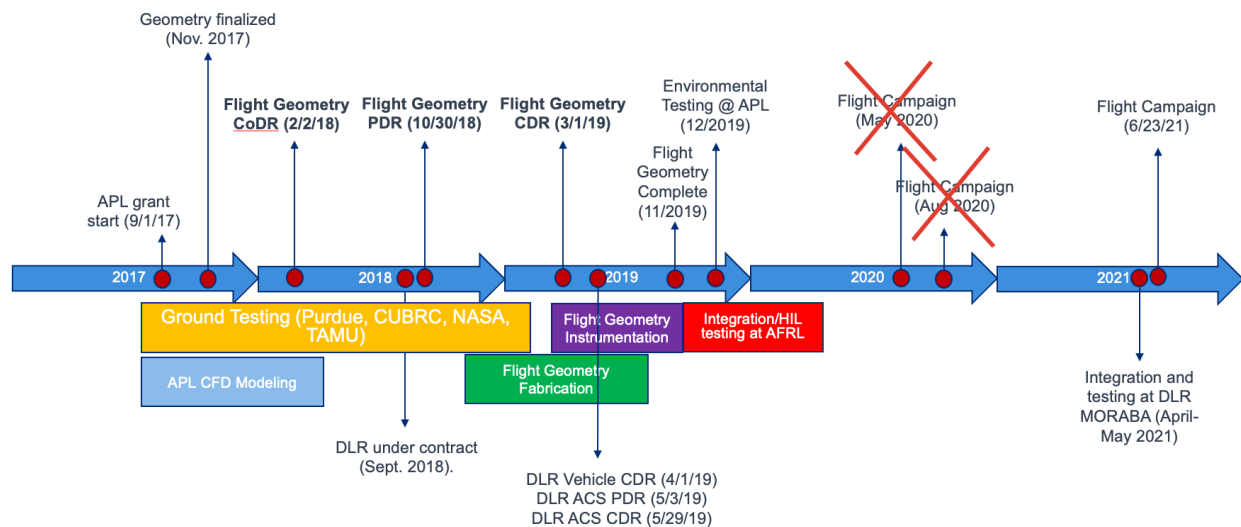


Figure 3. Overall BOLT project timeline

Table 1. Major meetings and events in the BOLT program

Date	Meeting Type	Location	Topic(s), Major Outcomes, Decisions
2017-09-01	Telecon	-	BOLT kickoff planning
2017-09-08	Review	APL	BOLT Kickoff
2017-09-21	In Person	APL	APL/RQ coordination, review of RQ systems, planning interface, LSP considerations
2017-10-06	Telecon	-	Finalized leading edge radius and geometry!
2017-10-19	Telecon	-	Discussed slight design changes to the gutter shape and showed CFD results of two designs
2017-11-08	DLR Tour	DLR sites	Met DLR MORABA team and discussed plans for BOLT flight
2017-11-29	In Person	APL	Internal review of aerodynamics by APL Steering Committee
2017-12-05	Telecon	-	Reviewed APL boundary layer stability results at flight conditions
2017-12-22	Telecon	-	CUBRC test planning
2018-01-10	Conference	AIAA SciTech 2018	Presented BOLT flight overview to transition open forum
2018-01-19	Telecon	-	Planning of flight requirements
2018-01-26	Review	-	Flight Experiment Requirements Review
2018-02-02	Review	BRICC, Arlington VA	Conceptual Design Review (CoDR)
2018-02-09	Review	-	CUBRC Test Plan Review
2018-05-19	Exhibition	Washington, DC	Military Invention Day 2018 at the Smithsonian American History Museum
2018-06-19	In Person	AEDC Tunnel 9, White Oak MD	Discussed Medtherm installation best practices
2018-06-22	Telecon	-	Science team update
2018-06-25	Conference	AIAA AVIATION 2018	Presented flight test planning and ground test results at BOLT special session
2018-07-13	Telecon	-	Summarize thermal modeling since CoDR in advance of materials selection
2018-07-18	Review	APL	Internal review of thermal modeling by APL Steering Committee

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Table 1. Major meetings and events in the BOLT program

Date	Meeting Type	Location	Topic(s), Major Outcomes, Decisions
2018-07-27	Telecon	-	Presented preliminary structural modeling
2018-08-10	Review	APL	Outbrief of final BOLT PhD intern summer research
2018-08-17	Telecon	-	Flight instrumentation planning with team
2018-08-24	Telecon	-	Trade studies on instrumentation numbers and types
2018-09-07	Telecon	-	Instrumentation ordering update, interface study on TZM/Stainless, review of Purdue entry from previous week
2018-09-10	In Person	APL	Pre-PDR meeting between APL and AFRL/RQ, new schedule, expectations, review design
2018-09-12	Exhibition	APL	BOLT display at APL Hypersonics Symposium
2018-09-14	Telecon	-	Review of collected science data for instrumentation layout discussions
2018-09-21	Telecon	-	Review of instrumentation v02 layout
2018-09-24	Telecon	-	Additional flight instrumentation discussion
2018-09-28	Telecon	-	Review of instrumentation v03 layout
2018-10-02	Telecon	-	Presentation of Sandia BiGlobal results by Neal Bitter
2018-10-09	Telecon	-	Review of instrumentation v04 layout
2018-10-12	Telecon	-	Review of instrumentation v04 layout
2018-10-15	Telecon	-	Review of instrumentation v05 layout
2018-10-30	Review	BRICC, Arlington VA	Preliminary Design Review (PDR)
2018-11-09	Presentation	Johns Hopkins University, Baltimore, MD	Seminar at JHU
2018-11-28	Telecon	-	Review of instrumentation v06 layout
2018-11-29	Telecon	-	Presentation of joint thermocouple options
2018-12-21	Telecon	-	Review of Purdue step experiments and APL CFD
2019-01-18	Telecon	-	Summary of DLR v1.1 trajectory heating compared to design Woomera trajectory
2019-01-25	Telecon	-	Quick look at APL structural analysis ahead of CDR
2019-01-07	Conference	AIAA SciTech2019	Presentation of ground test results at AIAA SciTech
2019-02-01	Telecon	-	Structural nonlinear analysis review
2019-02-08	Telecon	-	Secondary experiment layout and planning of sensor boards
2019-02-11	Telecon	-	Review of instrumentation v07 layout
2019-02-14	Telecon	-	Planning of secondary experiment step height sizes
2019-02-15	Telecon	-	Planning of secondary experiment step height sizes
2019-02-18	Review	APL	Structural analysis review by APL Steering Committee and technical SME's
2019-03-01	Review	APL	Critical Design Review (CDR)
2019-03-06	Telecon	-	Quality check on CAD instrument holes versus specified locations
2019-03-12	Telecon	-	Specification of single vs dual channel Medtherms for secondary side
2019-04-01	Review	BRICC, Arlington VA	DLR Critical Design Review (CDR)
2019-04-12	Telecon	-	Fabrication and assembly photos to team
2019-04-24	In Person	APL	Tour and meeting with Dale Watring of Medtherm Corporation
2019-04-26	Telecon	-	Update on fabrication, nosetip coating, and inspection techniques
2019-05-03	Review	Telecon	DLR Attitude Control System (ACS) Preliminary Design Review (PDR)
2019-05-15	Review	Telecon	APL fairing and TSM thermal analysis
2019-05-29	Review	Telecon	DLR Attitude Control System (ACS) Critical Design Review (CDR)
2019-06-07	Telecon	-	Summary of final isolator design and attempts to quantify joint steps
2019-06-11	Exhibition	APL	Booth at Force Projection Sector "Town Hall"
2019-06-16	Conference	AIAA AVIATION 2019	Transition discussion group
2019-07-02	Telecon	-	Status on instrumentation
2019-07-19	Review	Telecon	Aerodynamic fairing structural final analysis
2019-08-02	Telecon	-	Update on instrumentation process, ballast, and fabrication of additional parts
2019-08-16	Telecon	-	Update on instrumentation and wiring
2019-09-13	Telecon	-	Update on instrumentation and wiring
2019-09-27	Review	APL	BOLT Science Team Hardware Sendoff Meeting

Continued on next page...

Table 1. Major meetings and events in the BOLT program

Date	Meeting Type	Location	Topic(s), Major Outcomes, Decisions
2019-10-11	Telecon	-	Fairing fabrication and mass properties
2019-10-25	Telecon	-	Update on wiring, instrumentation, and fabrication
2019-10-28	Presentation	NASA Wallops	Overview for BOLT II kickoff
2019-11-15	Telecon	-	Update on final delivery of BOLT payload
2019-12-06	Telecon	-	Update on environmental testing of payload at APL
2020-01-17	Telecon	-	Update on payload integration
2020-01-31	Telecon	-	Update on joint step measurements taken at AFRL
2020-02-28	Telecon	-	Planning for initial May 2020 flight campaign
2020-03-13	Telecon	-	COVID-related flight delays and replanning of flight campaign
2020-03-27	Telecon	-	COVID-related flight delays and replanning of flight campaign
2020-04-10	Presentation	Telecon	Daniel Araya virtual CalTech seminar
2020-04-13	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-04-24	ZoomGov	-	Purdue updated joint step mold measurements
2020-05-08	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-05-29	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-06-03	ZoomGov	-	APL internal COVID travel requirements planning
2020-06-12	ZoomGov	-	APL internal COVID travel requirements planning
2020-06-15	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-07-15	MS Teams	-	BOLT overview presentation for HYFLITS team
2020-07-17	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-09-11	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-10-09	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-10-23	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-11-06	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2020-12-04	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2021-01-29	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2021-03-12	ZoomGov	-	COVID-related flight delays and replanning of flight campaign
2021-03-18	ZoomGov	-	Electronics and wiring/integration overview for BOLT2 CUBRC team
2021-04-09	ZoomGov	-	Planning for DLR integration and testing travel
2021-04-16	Review	-	AFRL Technical Review Board for BOLT flight test
2021-04-27	Presentation	APL	Overview of BOLT for ONR Code 35
2021-04-29	Presentation	-	Overview of BOLT for NATO AVT-346 working group on BLT
2021-05-07	ZoomGov	-	Update on DLR environmental testing
2021-05-21	ZoomGov	-	Update on DLR environmental testing
2021-06-01	Review	-	Esrangle Space Center Pre-Campaign Safety Briefing
2021-06-04	ZoomGov	-	Flight Campaign final planning
2021-06-23	Launch	Esrangle Space Center	BOLT launch
2021-06-24	Review	Esrangle Space Center	Initial Post Flight Review at Esrange
2021-08-27	ZoomGov	-	Update to science team
2021-09-20	Review	-	BOLT Postflight Interim Review
2021-09-24	ZoomGov	-	Update to science team
2021-10-19	Meeting	-	NATO working group on BL transition, update on BOLT flight
2021-11-19	Review	-	BOLT Investigation Review

3. Financial Execution

A specified deliverable of the FA9550-17-2-0001 grant was to provide a “final budget” for the project to prepare and execute the flight experiment. Data were extracted from the APL financial system, in which all timekeeping expenses are tracked in accordance with Government regulations. These data are shown in this section.

The total funding allocated the present grant was \$2,216,430, provided in six increments as in

Table 2. The grant date began on 1 September 2017 and concluded on 30 November 2021 after receiving no cost extensions to cover delays in the flight test due to the COVID-19 global pandemic.

Table 2. Grant funding profile

Executed	Increment (\$)
1-Sep-17	1,184,231
1-Jul-18	49,430
1-Sep-18	450,570
1-Apr-19	150,000
28-Jun-19	365,199
18-Nov-20	17,000

Figure 4 shows a time history of the spending by APL on the current grant over the entire period of performance. The funding profile is shown in green reflecting the receipt of increment from AFOSR. The cumulative total spending is shown in dark blue. The majority of the spending was on APL labor, reflected as the orange curve. Purchasing is shown in yellow and this category covers the ground and flight test hardware and instrumentation purchases. Subcontracts to CUBRC and VirtusAero LLC for wind tunnel testing and computational analysis are shown in the grey curve. Finally, the light blue curve shows travel costs associated with travel by APL personnel to support various testing events including the final flight campaign. The figure shows the majority of spending occurring between September 2017 and December 2019 reflecting the bulk of the project effort to deliver the completed flight experiment hardware to the US Air Force in November 2019. A long delay due to COVID-19 can be seen as the relative flattening of the spending curve until the final flight campaign in June 2021. A breakdown of the total spending by type is shown in Figure 5.

APL labor was tracked via a Work Breakdown Structure (WBS) as described in Table 3. APL staff were directed to charge the appropriate budget to loosely track the labor effort required in each category. These data are shown as a cumulative pie chart in Figure 6 as a proportion of total APL labor effort. It should be noted that the “CFD” category is probably underrepresented as Computational Fluid Dynamics methods were used as an integral portion of ground and flight test analysis and design. The “CFD” labor budget mainly reflects time spent on the generation of a computational grid and database of flow solutions, and follow on analysis with those results was done under the other budgets. It can be seen that the largest labor categories were the mechanical design and fabrication support of the ground and flight hardware (DES) followed by the design and execution/analysis of the flight test (FLT). Another large labor category was the task management (MGT) which included documentation and reporting as well as coordination of the individual technical activities.

The labor spending by WBS are also shown for each month in the project in Figure 7. This figure shows the breakdown of activities in each WBS versus time. The beginning of the grant featured the highest monthly labor spending rates reflecting the wide variety of activities in the first two years of the grant, focused on obtaining ground test data and designing the flight experiment. This figure also shows the reduced spending during the COVID-19 delays from March 2020 to

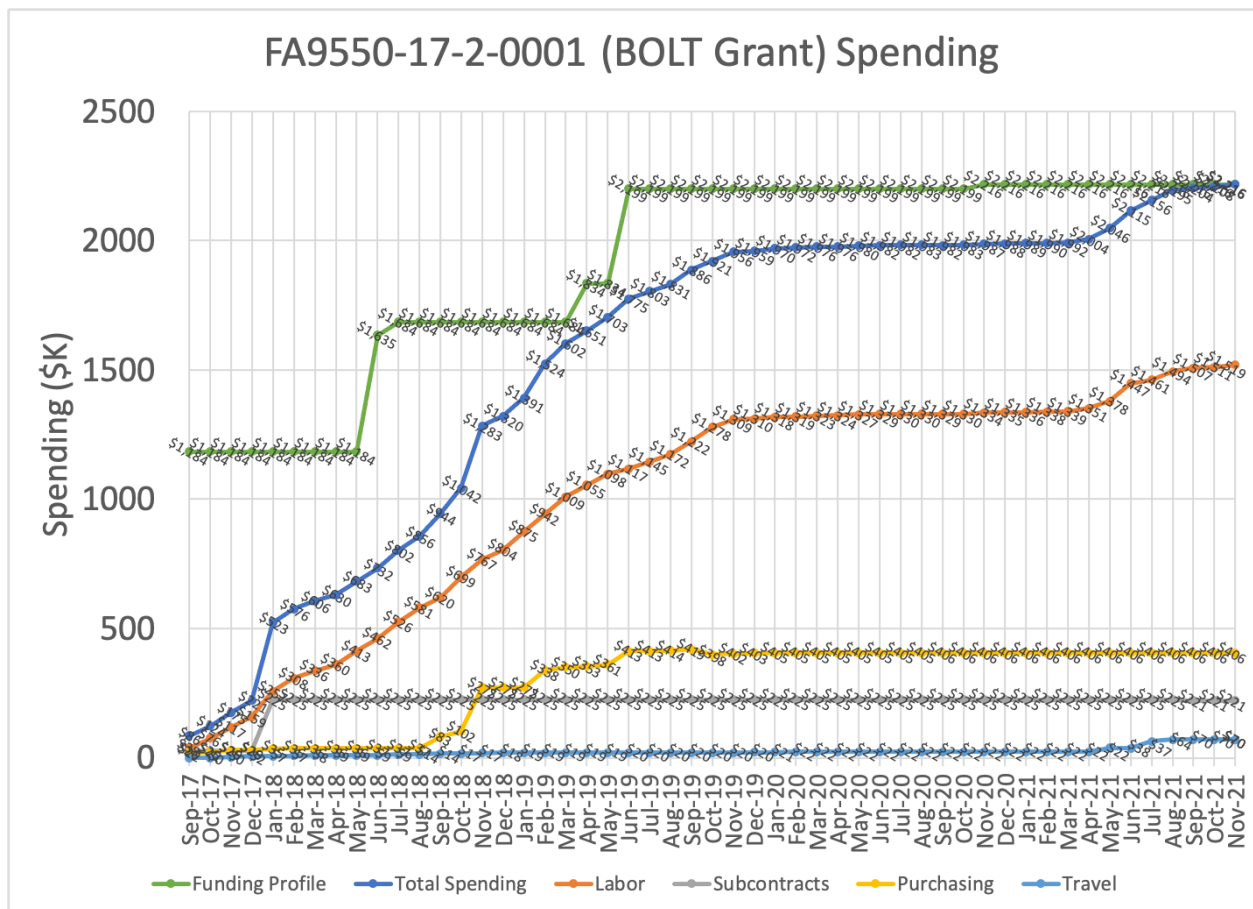


Figure 4. Grant financial spending (\$K) history throughout the period of performance

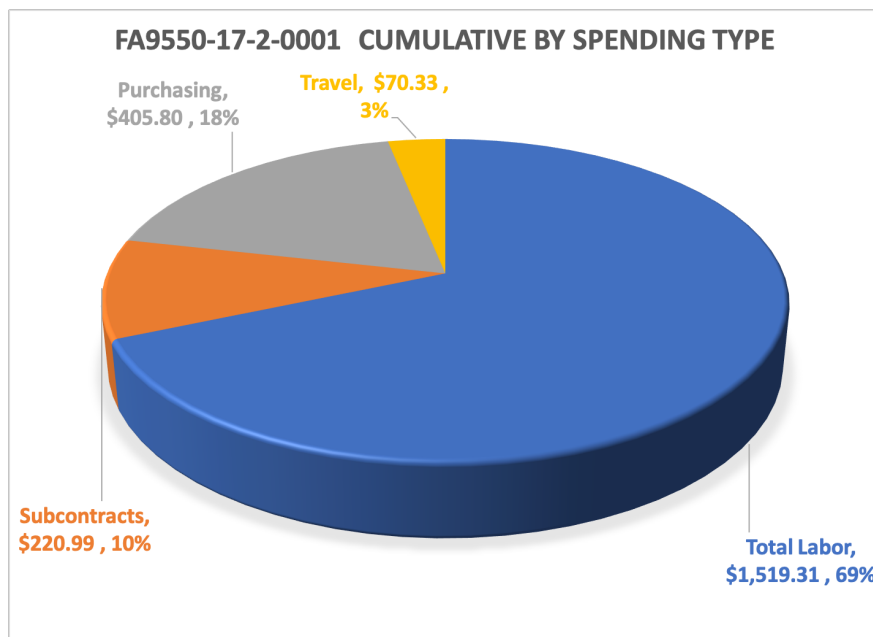


Figure 5. Breakdown of total spending (\$K) by category (“Purchasing” includes material and miscellaneous other costs)

March 2021, followed by a sharp uptick in spending due to international test activities in Germany and Sweden from April 2021 through June 2021.

Table 3. Descriptions of the work-breakdown structure (WBS) used by APL to track labor and purchases for BOLT

WBS	Description	Activities
CFD	Computational Fluid Dynamics	Computational simulations and boundary layer stability supporting experiment design
DES	Mechanical Design Support	Mechanical design of ground test articles and Flight Geometry. Thermal and structural analyses. CFD work supporting thermal analysis. Mechanical support of fabrication and instrumentation activities.
FAB	Fabrication	Fabrication of ground test articles, Flight Geometry, and related support hardware.
FLT	Flight Test Planning/Execution	Design of the flight experiment including instrumentation layout and secondary experiment. Support of integration and testing activities at DLR MORABA. Support of flight campaign and post-flight analysis.
GRT	Ground Test Planning/Support	Planning and execution of all ground testing related activities.
MGT	Management and Reporting	Preparation and briefing of BOLT team status updates. Reporting including annual and final report deliverable. Planning and execution of meetings including design reviews and exhibitions.
INS	Instrumentation	Installation and wiring of all flight instrumentation and electronics.

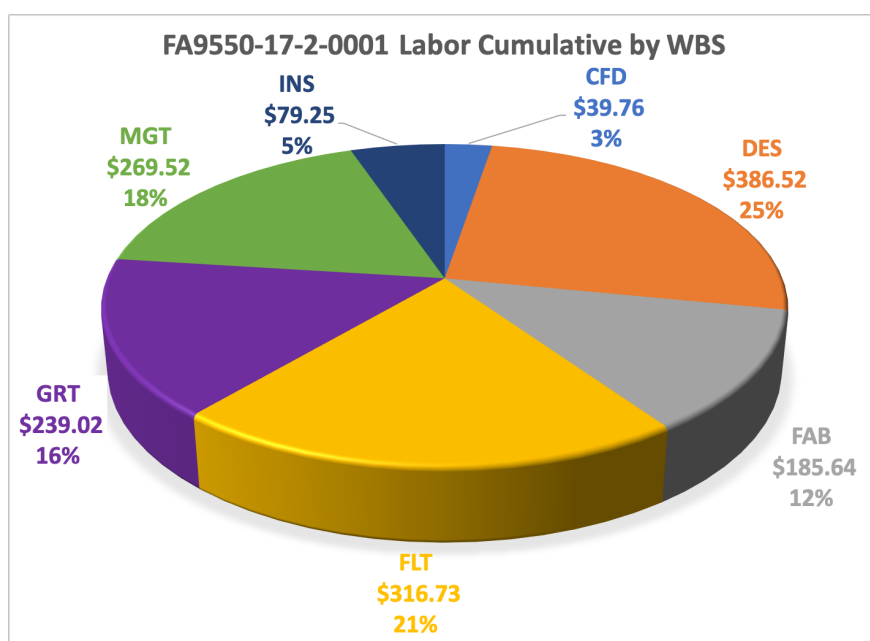


Figure 6. Breakdown of total labor spending (\$K) by WBS tracking category (CFD = computational and stability work, DES = ground and flight test mechanical design, FAB = ground and flight test fabrication costs, FLT = flight test planning and execution, INS = instrumentation installation and wiring, GRT = ground test planning and execution, MGT = project management costs)

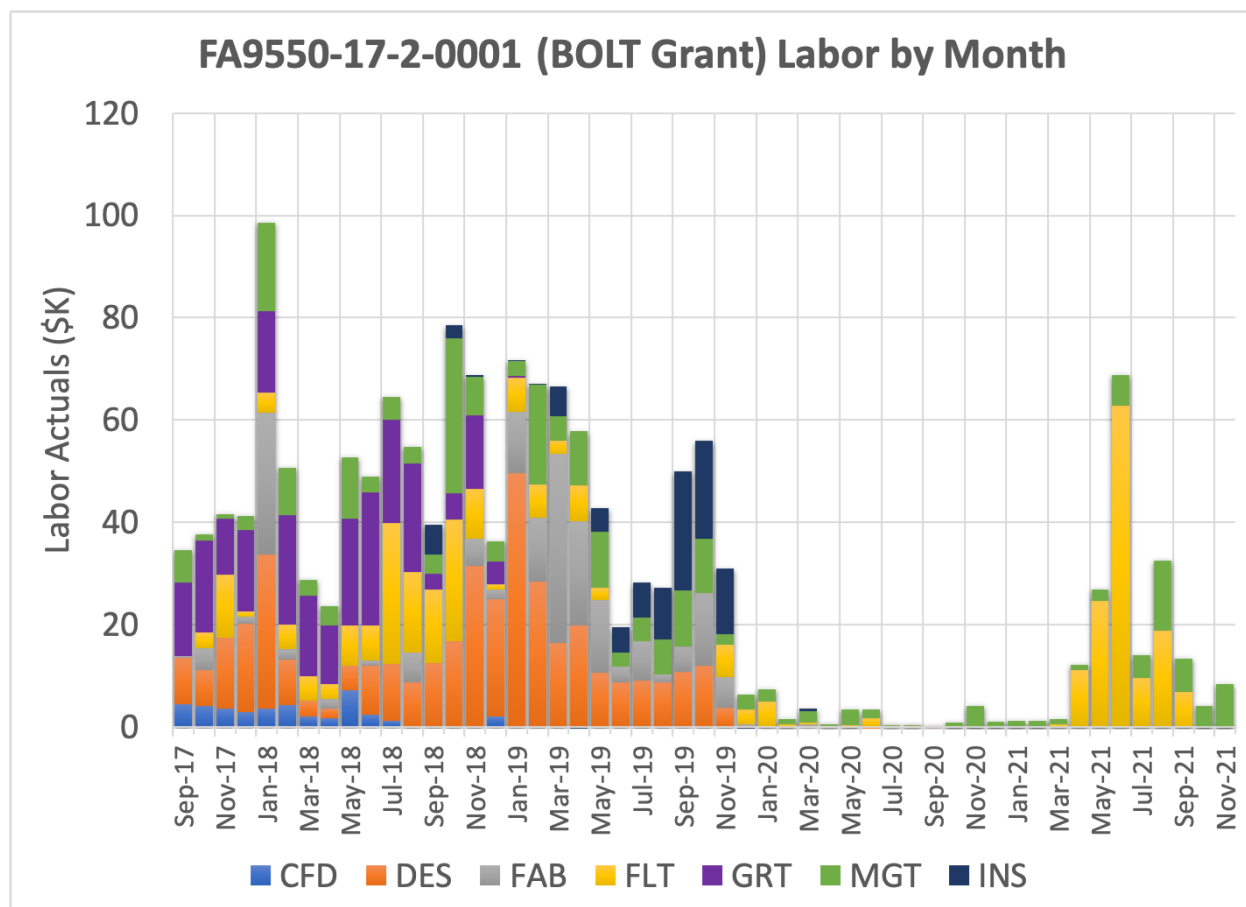


Figure 7. Monthly labor spending (\$K) by WBS tracking category (CFD = computational and stability work, DES = ground and flight test mechanical design, FAB = ground and flight test fabrication costs, FLT = flight test planning and execution, INS = instrumentation installation and wiring, GRT = ground test planning and execution, MGT = project management costs)

4. Deliverables

This section provides a summary of the APL deliverables. A reminder of the list of deliverables required for this project is shown in Table 4. Newly completed deliverables (highlighted in yellow in the table) are provided as supplements to this annual report, and will be provided to the AFOSR PO (Dr. Popkin) as well as archived on the APL Box share drive used to store deliverables.

Table 4. BOLT grant deliverables from APL to AFOSR

Task	Description	Status	Comments
Task 2	Ground test articles(s)	Delivered	Model final drawings, CAD, and related design analysis archived in Box share. Drawings in Appendix A.1 of Year 3 report.
Task 2	Ground test data	Delivered	Archived in Box share. Description of data in Appendix A.2 of Year 3 annual report.
Task 2	Ground test report that documents the test planning, test execution, data processing, results and discussion	Delivered	Archived in Box share. Delivered as a report dated 31 August 2021.
Task 3	Summary of similarities and discrepancies between ground test data and numerical simulations in task 1 and plausible explanations for the discrepancies	Delivered	Included in this final report
Task 6	Detailed design specifications for the Flight Geometry sufficient for the geometry to be manufactured	Delivered	Model final drawings, CAD, and related design analysis archived in Box share. Drawings in Appendix A.3 of Year 3 report.
Task 7	Flight Geometry	Delivered	Delivered to AFRL/RQ in November 2019
Task 7	Assembly instructions	Delivered	Archived in Box share. Delivered as a report dated 31 August 2021.
Task 7	Quality inspection report	Delivered	Archived in Box share. Delivered as a report dated 31 August 2021.
Task 9	As-built instrumentation documentation after model instrumentation is complete, to include check-out procedures, sensor operational status	Delivered	Archived in Box share. Description of data in Appendix A.5 of Year 3 annual report. Macro photographs from flight campaign added to Box share.
Task 13	Final report and plan to make the data from the project readily available to future AFRL/AFOSR teams	Delivered	Included in this final report
Task 14	Final schedule	Delivered	Included in this final report
Task 14	Final budget	Delivered	Included in this final report

5. Flight Experiment Summary

This section will describe the actual vehicle behavior during the BOLT flight utilizing the “best estimate trajectory” (BET) from the vehicle Inertial Measurement Unit (IMU) and Global Position System (GPS) receivers, as well as the “best estimate atmosphere” (BEA) provided by the U.S. Air Force Weather Agency based on global weather model anchored with discrete weather balloon soundings at the range. A description of available transition measurements during the ascent and descent phases of flight will be provided. The final characterization of the vehicle trajectory and attitude will continue under a follow-on grant to APL for post-flight data analysis.

5.1. Flight Dynamics Axis Definitions

Descriptions of the vehicle motion are provided relative to a flight dynamics axis reference system shown in Figure 8, viewed from the front of the vehicle. The axes are body fixed with an origin at the vehicle center of gravity. The X (roll) axis points forward, with the lateral axes Y and Z describing pitch and yaw motion, respectively. A positive angle of attack (α) is achieved by a positive rotation about the Y (pitch) axis, and a positive sideslip angle (β) is achieved by a positive rotation about the Z (yaw) axis. The total angle of attack (α_T) is defined as the included angle between the vehicle X axis and the incoming wind vector, and represents the magnitude of both α and β by the relation:

$$\tan^2(\alpha_T) = \tan^2(\alpha) + \tan^2(\beta) \quad (1)$$

Rays of the vehicle are denoted 0–360° in Figure 8 and will be used to report the windward meridian angle of the flow. The windward meridian is the vehicle azimuthal angle that is windward with respect to the incoming velocity vector. The windward meridian is 0° when the primary experiment surface is windward and 180° when the secondary experiment surface is windward.

5.2. Best Estimate Trajectory

Analysis of the BOLT flight BET is still ongoing, but the latest BET is shown in Figure 9. A divergence of the vehicle from the nominal trajectory occurred at approximately 11 s into flight, near or shortly after separation of the first stage S31 motor. The vehicle flight continued as planned with the payload remaining attached to the second stage Improved Orion (IO) motor, however due to the increased drag from the unexpected behavior the maximum Mach number achieved was 3.9 instead of 7.0.

The vehicle flight dynamics during the ascent phase from liftoff until 35 s are shown in Figure 10. The Mach number and dynamic pressure from the ascent are shown in Figure 10a. Maximum dynamic pressure occurred during stage separation at 11.1 s at an altitude of 5.6 km. Near that time, the vehicle experienced a positive pitching motion nearly entirely about the Y axis resulting in growth of total angle of attack from small values less than 0.5° to 7–7.5° in just a few seconds. The vehicle became locked into the flow with a windward meridian angle near the 180° ray (secondary surface experiment windward). The ignition of the IO motor occurred at 15.1 s at $\alpha_T = 7^\circ$, resulting in a further angle of attack increase to values of α_T near 20° presumably due to the thrust axis misalignment with the vehicle flight path. The divergent flight behavior is also indicated the the AFRL/RQ IMU data showing large nonzero lateral rates about the yaw axis (Figure 10e) and yaw

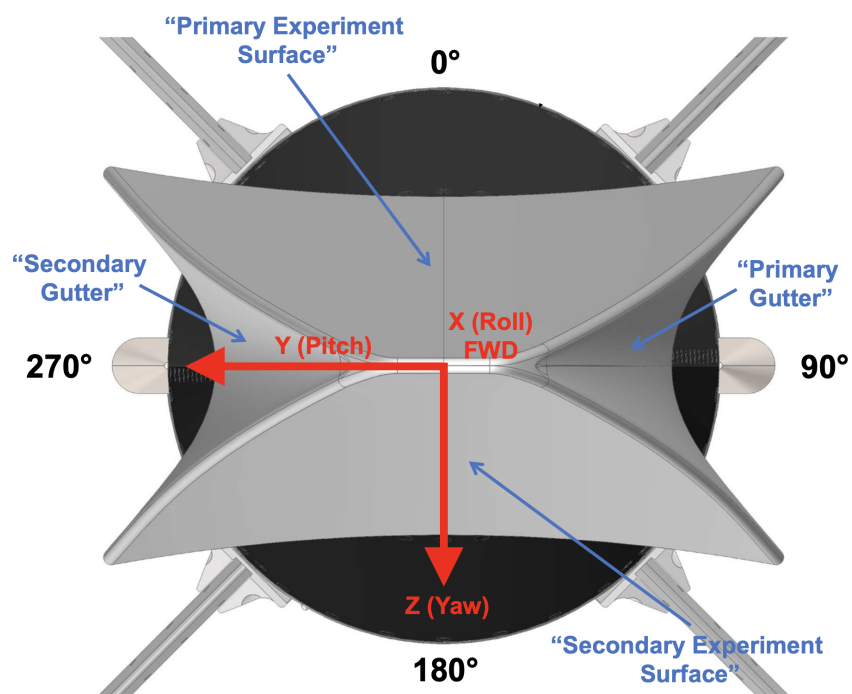


Figure 8. Axis definitions for descriptions of flight dynamics (view forward looking aft).

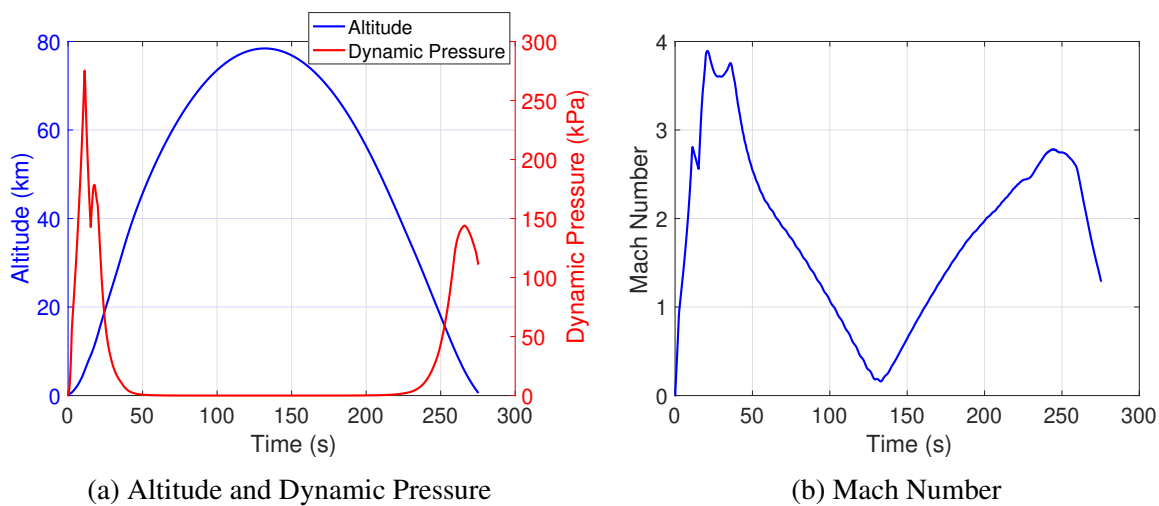


Figure 9. Best Estimated Trajectory (BET)

axis lateral acceleration (Figure 10f). Data suggests that the vehicle entered into pitch-roll coupling at a rate of approximately 500°/s shortly after 11 s and remained in this state throughout most of the ascent. The lock-in of the windward meridian during this time can be described as “lunar motion,” in which the vehicle rotates about the wind vector but the same side of the vehicle is facing the incoming wind vector.

An analysis of the descent phase of flight from approximately 220 s until 275 s is ongoing and will be reported in the final paper. Two IMU’s were on board and data are being used to reconstruct the vehicle attitude on descent. The DLR MORABA roll-stabilized IMU saturated due to the high angular rates during ascent, and the data from this IMU are not useful post-saturation. A second IMU provided by AFRL/RQ is available but is not roll-stabilized, and work is ongoing to integrate the IMU data into an estimated vehicle attitude solution during descent. Due to the buildup of small errors and drifting in the solution, there is currently some disagreement in the exact vehicle attitude during descent. However, the flight velocity and altitude are well known from GPS data and are sufficient to report the Mach number and Reynolds numbers during descent at this time.

5.3. Pressure Sensor Flight Attitude Reconstruction

Measurements of the mean surface pressure on the BOLT forebody for the entirety of flight were collected on eight Kulite pressure transducers. These measurements were intended to capture the changes in pressure due to the vehicle rolling at a small angle of attack and use that to recreate the vehicle attitude. This would then provide a separate method to verify that the GPS and IMU were providing accurate measurements of the vehicle. The recreation of vehicle attitude was completed by minimizing the rms difference between the flight measurements and a computed surface pressure, similar to Jewell et al. [11]. The rms difference was defined as

$$p_{RMS} = \frac{1}{p_{\infty}} \left[\frac{1}{8} \sum_{i=1}^8 (p_{CFD} - p_F)_i^2 \right]^{0.5} \quad (2)$$

This method will minimize the effects of individual sensors malfunctioning or having poor calibrations. The computed pressures were extracted from a CFD database generated with CART3D. CART3D is a high-fidelity inviscid CFD package with a fully integrated adjoint-driven mesh adaptation. The database spanned the range of α_t , ϕ (aerodynamic roll angle), and Mach number for the entirety of the flight. The range of conditions is shown in Table 5. For every time step, the database was interpolated to the correct Mach number and then interpolated again to a finer resolution of α_t and ϕ . The rms difference was then calculated and minimized to find the correct α_t and ϕ . Figure 11 shows an example of this process.

5.4. Potential Transition Experiment Conditions

An analysis of potential transition experiment conditions, albeit at supersonic Mach numbers rather than hypersonic conditions, was completed using the BET and the BEA to compute Mach number and Reynolds number for the ascent and descent phases. As mentioned previously, the IMU

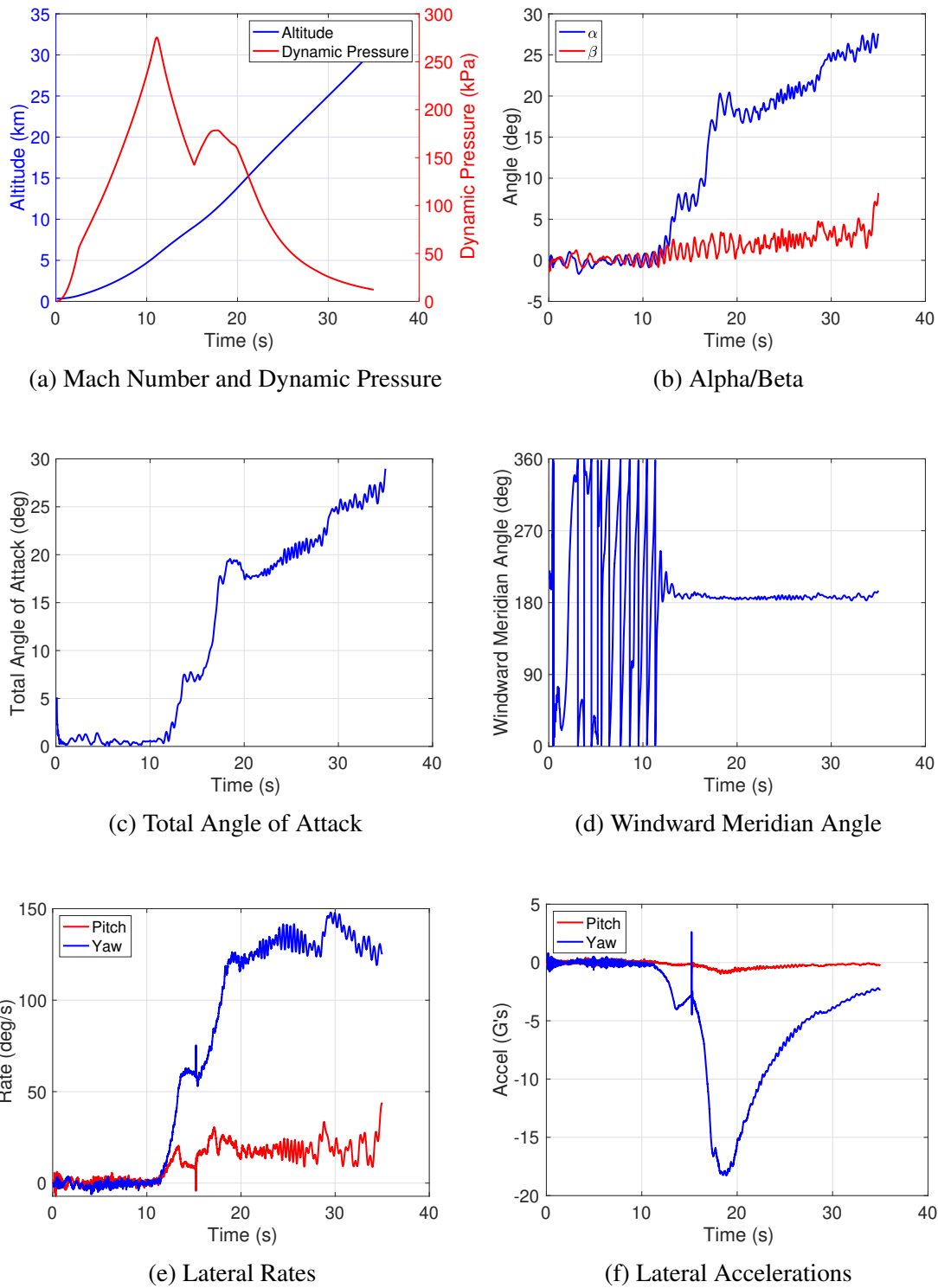


Figure 10. Ascent phase vehicle flight dynamics from 0–35 s

Table 5. Range of conditions for CART3D CFD database

Variable	Range
α_t	0–25 degrees
ϕ	0–360 degrees
M	1.5–4.5

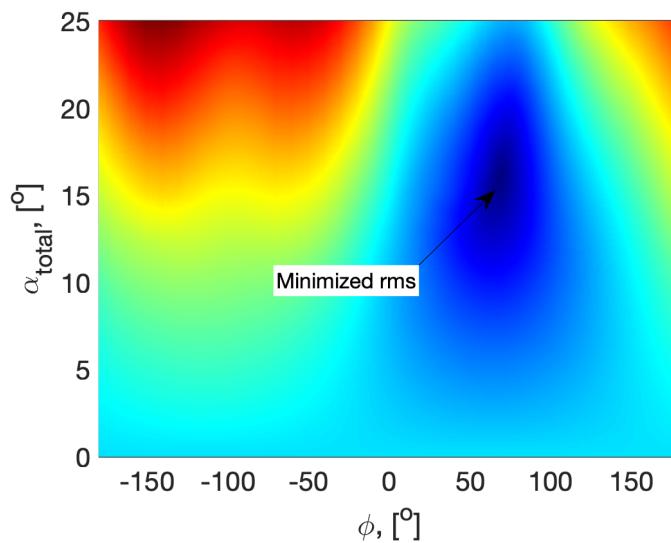


Figure 11. Example of rms differences for a given Mach number.

attitude solution during descent to compute angle of attack is still preliminary but is considered reasonably well characterized early in flight. Using the length of the BOLT Flight Geometry (0.866 m) a length Reynolds number (Re_L) was computed for both the ascent and descent phases and summaries of vehicle Mach number and attitude are presented in Figure 12 and 13. These figures essentially convert the flight time into the experiment Reynolds numbers, replacing the horizontal axes of the figures.

The ascent vehicle dynamics were already previously described in Section 5.2 and are shown again in terms of Reynolds number in Figure 12. The original BOLT experiment Reynolds number of interest were $Re_L = 0\text{--}20 \times 10^6$, during which it was expected to achieve natural transition. Although transition Reynolds number typically varies with Mach number, no pre-flight ground testing or analysis was performed at supersonic conditions, and it is assumed that transition onset should still occur within this relatively broad range of Re_L . Examination of Figure 12 shows that the majority of flight conditions in the $Re_L = 0\text{--}20 \times 10^6$ during ascent occurred at relatively large angles of attack in the range of $17\text{--}30^\circ$. In addition, the secondary side of the experiment was windward with respect to the incoming velocity vector during this entire period. The primary side was thus leeward to the flow, and unfortunately it contained the majority of the flight experiment sensors. Some useful transition data might be achieved from the ascent phase of flight but due to the high angles of attack it was decided to focus on the descent phase of flight.

The BOLT descent phase of flight in terms of Reynolds number Re_L is shown in Figure 13. Preliminary data suggests that the BOLT vehicle entered the atmosphere with large oscillations in attitude due to the lack of a reorientation maneuver (as originally was planned for nominal flight). However, the vehicle does appear to have gradually aligned with the flight path vector as it reentered the atmosphere. This can be seen in Figures 13b and 13c. Two sets of data are shown for angles of attack reflecting the current uncertainty in the current IMU solution (blue) and the orientation derived from pressure sensors on the forebody (red). It seems likely that the actual vehicle attitude is closer to the forebody pressure derived (red) data. The forebody pressure solution would also indicate that the vehicle re-entered lunar motion with the secondary side windward for the majority of the descent phase, although at a much lower total angle of attack ($2\text{--}3^\circ$) than that of the ascent. Follow-on research performed by APL will produce an agreed upon solution for the vehicle attitude during descent that will correspond with the analysis of the BOLT Flight Geometry science data.

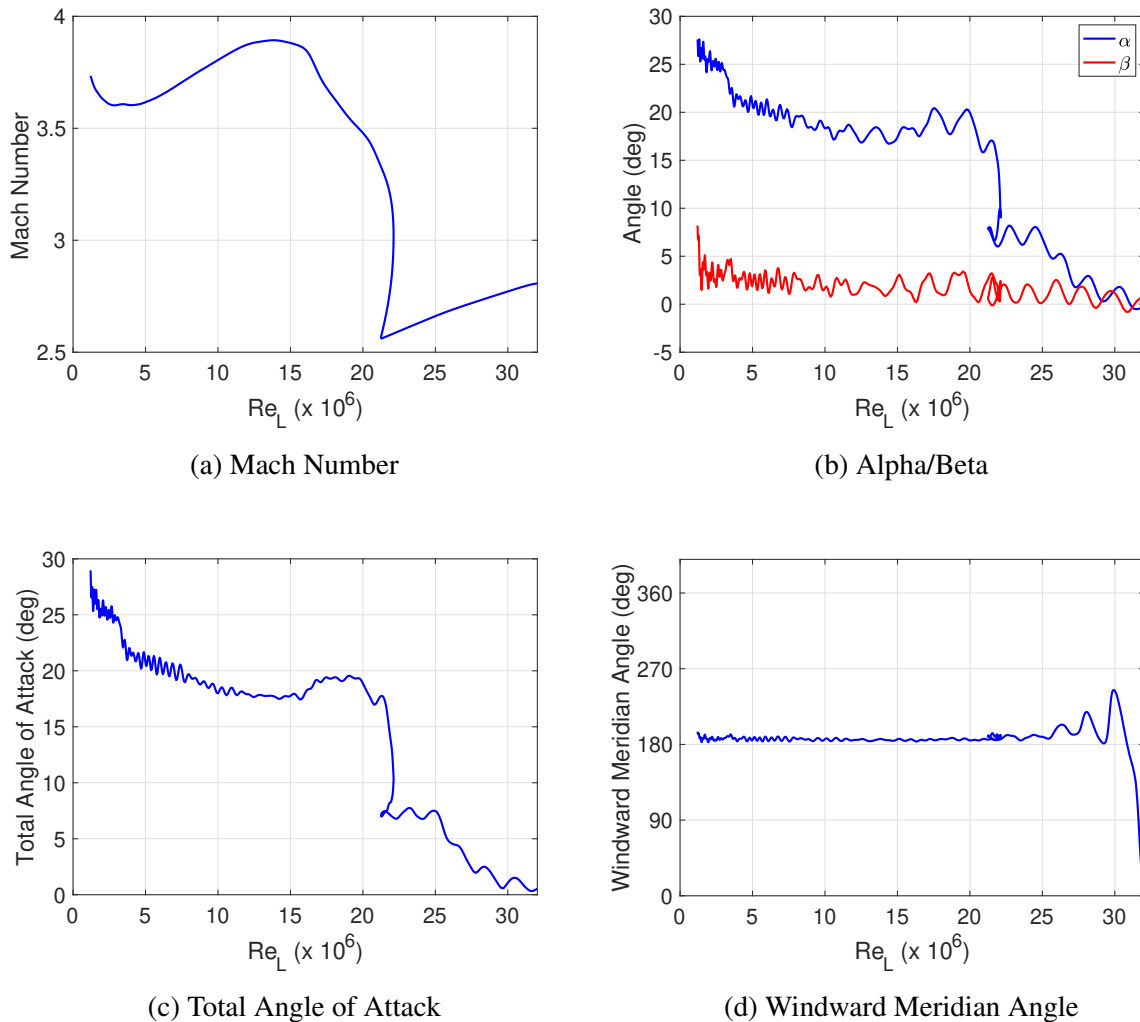
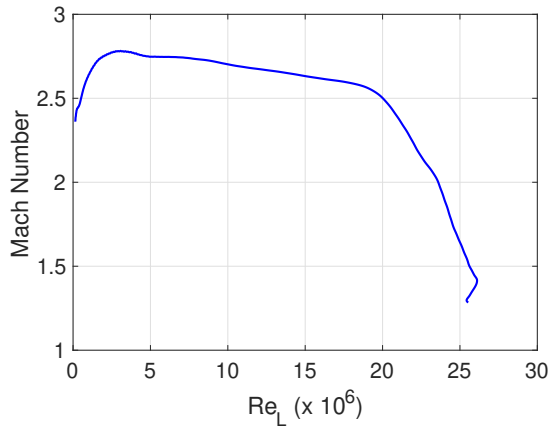
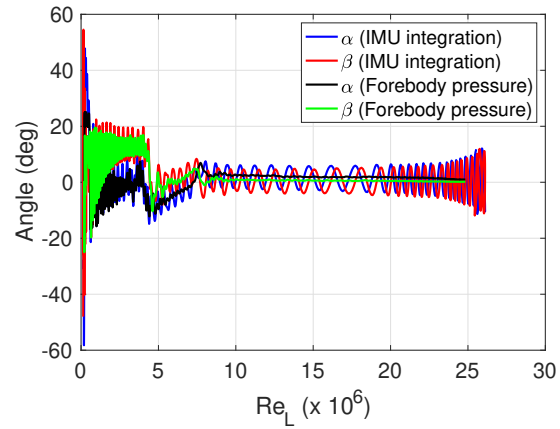


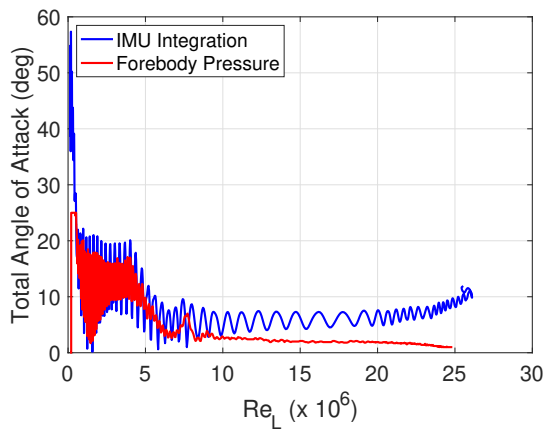
Figure 12. Ascent phase experiment conditions from 11.3 s to 35.0 s, plotted against the length Reynolds number of the BOLT Flight Geometry (0.866 m)



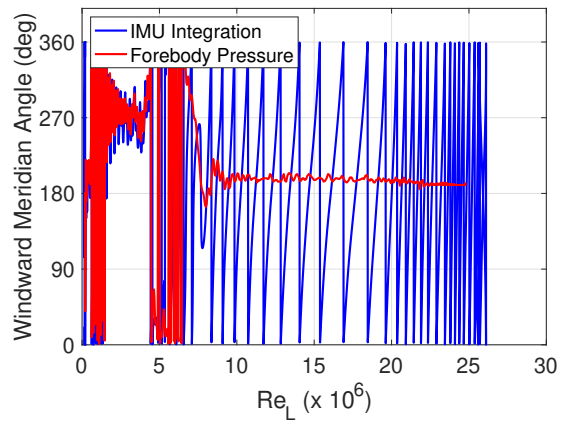
(a) Mach Number



(b) Alpha/Beta



(c) Total Angle of Attack



(d) Windward Meridian Angle

Figure 13. Descent phase experiment conditions from 220 s to end of flight, plotted against the length Reynolds number of the BOLT Flight Geometry (0.866 m)

6. Summary of Similarities and Discrepancies Observed between BOLT Pre-Flight Ground Tests and Numerical Simulations (Task 3 Deliverable)

A deliverable specified by the current grant was to summarize the similarities and discrepancies observed between BOLT pre-flight ground tests and numerical simulations, as well as the final flight data. Because the final flight conditions did not match the intended Mach numbers from preflight computational and ground testing analysis, a summary of observations between computational and ground test results will be provided.

This section provides a summary of the similarities and discrepancies observed between BOLT pre-flight ground tests and numerical simulations. The purpose of the pre-flight testing and simulation was both to provide inputs to the final flight vehicle design as well as to probe the fundamental boundary layer physics unique to BOLT.

Pre-flight numerical simulations included the following:

- mean flow computations utilizing CFD++, US3D, and DPLR codes
- linear and nonlinear boundary layer stability computations utilizing LSTRAC, STABL, STABL3D, EPIC, and BiGlobal codes
- steady and forced Direct Numerical Simulations using US3D.

Pre-flight ground testing included entries at the following facilities:

- Purdue Mach 6 Quiet tunnel
- CUBRC LENS II
- NASA Langley 20-inch Mach 6 tunnel
- Texas A&M ACE and Mach 6 quiet tunnels

A summary of the conditions for the pre-flight data analyzed is shown in Figure 14 with the nominal trajectory experiment windows highlighted for reference. Due to facility limitations, a majority of the ground tests were conducted at conditions close to Mach = 6 and $Re_L < 5e6$, which corresponded to the end of the ascent experiment window. The full-scale test at the CUBRC LENS II facility was the only ground-test data obtained for early in the ascent experiment window (Mach < 5.5) as well as during the planned descent experiment window (Mach > 7).

Of primary interest from all of the pre-flight data collected were observations of the following: (a) the shape and movement of the boundary layer transition front, (b) laminar and turbulent surface heating levels, and (c) frequencies of pressure fluctuations relevant to boundary layer instabilities.

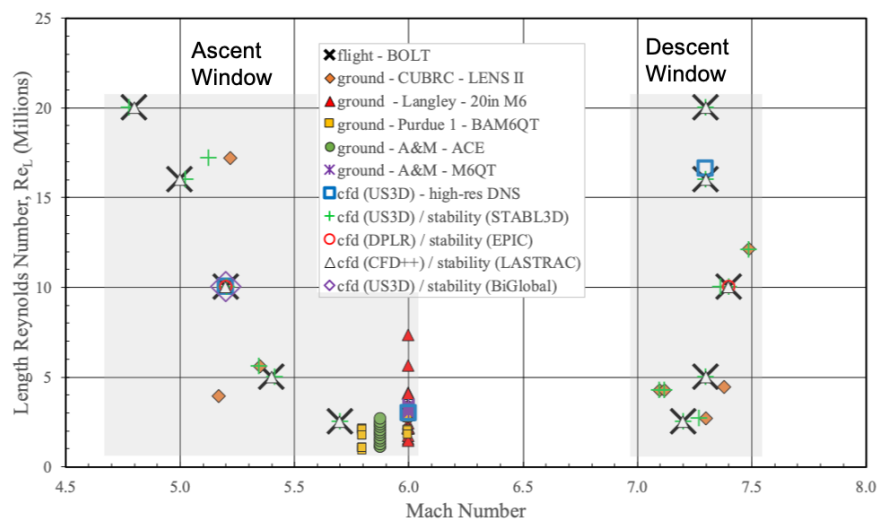


Figure 14. Summary of conditions for BOLT pre-flight ground tests (solid symbols) and numerical simulations (open symbols) conducted before PDR (October 2019).

Natural transition was not observed in any of the quiet tunnel tests conducted before the flight. In lieu of this, tunnel data from NASA Langley and CUBRC along with laminar CFD was used to assess the shape and movement of the transition front that was anticipated in flight. An example of surface heating data collected from an August 2017 NASA Langley test of a subscale BOLT model is shown in Figure 15. A notable feature in this data is the appearance of wedges of elevated heating on the outboard edges of the model as the Reynolds number is increased, an indication of transition to turbulent flow. Also notable is the strong sensitivity of the shape of the outboard wedges with changes in yaw orientation. Only a slight increase in heating was observed with increasing angle of attack while preserving the general shape of the transition front.

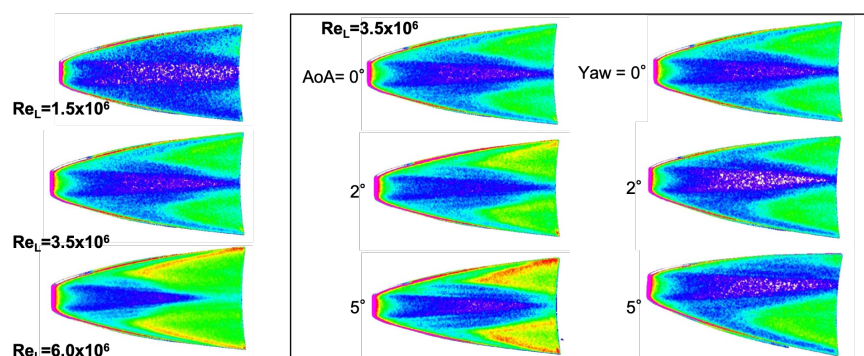


Figure 15. Langley surface heat flux measurements with Re , AoA , and Yaw variations.

Figure 16 shows an example of surface heating data from the CUBRC test combined with laminar CFD that was used to assess the transition front at flight conditions. The ratio of temperature

sensitive paint (TSP) measurements from the experiment relative to laminar CFD predictions of heat flux are shown in the figure as a colored surface contour. Spherical symbols represent surface instrumentation (Medtherms, Kulites, Vatelts). Red symbols indicate a turbulent assessment at a given sensor (ratio > 1.75) and blue symbols indicate a laminar assessment. The estimated transition front can be seen to take on a complex shape with peaks both along outboard edges as well as along the centerline.

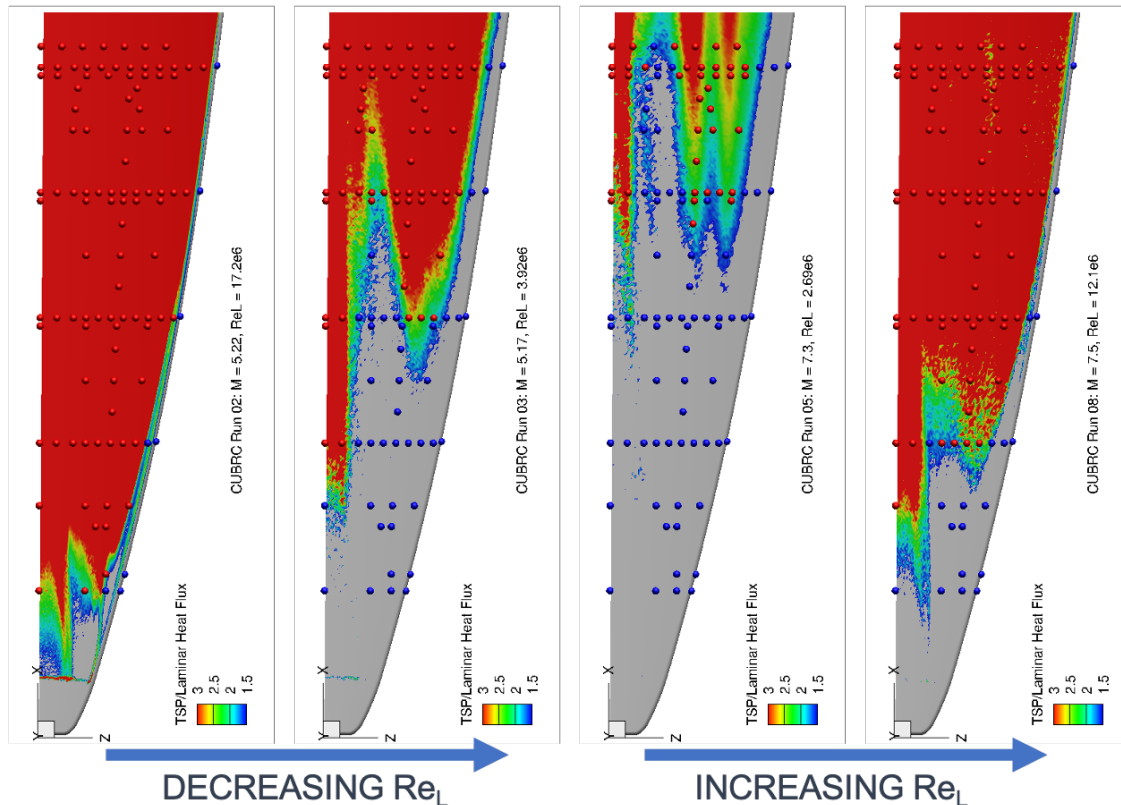


Figure 16. Transition front assessment based on CUBRC measurements and laminar CFD predictions.

Boundary layer stability computations were conducted to assist in planning surface sensor placement both on the ground and during flight to try to measure the growth of boundary layer instabilities. A sample of these stability computations to predict maximum N-factors for second-mode, stationary crossflow mode, and near centerline instabilities for different trajectory conditions are shown in Figure 17. A few observations can be made from this figure relative to the experimental measurements shown in Figures 15 and 16. First, one-dimensional linear stability analysis (LASTRAC, EPIC) of second-mode and stationary crossflow modes predict that these modes dominate in the midspan region, with $N > 7$ forming a similar transition wedge pattern to that seen in the surface heating measurements at Langley and other tunnels. Second, the BiGlobal analysis uses a higher fidelity method than either LASTRAC or EPIC and its predictions of centerline instabilities tending to dominate for ascent conditions (Mach = 5.2; $Re_L = 10e6$) qualitatively agree with the surface heat flux pattern seen in the CUBRC data. Furthermore, despite the large second-mode

N-factors predicted by the one-dimensional stability analysis (LASTRAC, EPIC), second-mode was not observed during the full-scale experiments at CUBRC. This discrepancy between the predictions and measurements at CUBRC could be attributed to several factors including (1) incorrect surface sensor placement, (2) too low signal to noise due to noisy tunnel operation, or (3) second-mode instability growth weaker than centerline instabilities for CUBRC LENS II conditions, as suggested by the BiGlobal analysis.

One of the prominent flow features seen in both high-fidelity CFD and quiet tunnel measurements for BOLT were streamwise laminar heating streaks. A qualitative comparison of numerical predictions from the University of Minnesota and experimental measurements at Purdue and Texas A&M are shown in Figure 18. A more quantitative comparison is shown in Figure 19. The Minnesota results were achieved using special numerics that minimize numerical dissipation in the computation, something the team dubbed “Quiet DNS” and which was developed during the course of the BOLT project.

Initially, there was a great deal of debate about the nature of these laminar streaks. Specifically, there was uncertainty about how the streaks originated and it was thought that they could either be the result of a crossflow instability, as indicated by the stability analysis, or simply a feature of the laminar flow field, as indicated by the high-fidelity (laminar) CFD. This debate centered around the question of the correct baseflow to use in the analysis. Figure 20 shows a comparison of two laminar computations utilizing different numerical schemes within separate codes (US3D and DPLR), with both considered to be “grid converged.” It was found that the laminar streaks that form downstream on the surface of BOLT are sensitive to both the grid resolution and numerical scheme utilized and that standard second-order dissipative fluxes add too much numerical dissipation to properly resolve all of the laminar flow features. By utilizing the low-dissipation baseflow within a higher-order nonlinear PSE stability calculation, the team was able to determine that the laminar streaks are indeed an instability resembling stationary crossflow and the receptivity mechanism is the vorticity generated by the curved bow shock at the nose.

A summary of the major similarities and discrepancies between pre-flight analysis and ground test results is thus as follows:

- Natural transition did not occur in quiet tunnels at available Reynolds numbers, however the quiet tunnel low disturbance environment allowed visualization of streamwise streak structures that are only captured in high-quality CFD simulations with low dissipation numerics.
- Under conventional/noisy flow, transition occurred at fairly low Reynolds numbers. Despite having high-frequency instrumentation within the transition region at several facilities, no definitive measurement of instabilities leading to transition was obtained under noisy flow.
- Under quiet flow, instabilities were measured only in the center vortex region of the geometry. These instabilities appear convective within the center vortex and assumptions made by typical linear LST and PSE methods appeared insufficient to model these. Forced DNS and BiGlobal methods did identify these instabilities, however.
- The linear LST and PSE codes did predict high crossflow N-factors in the outboard region

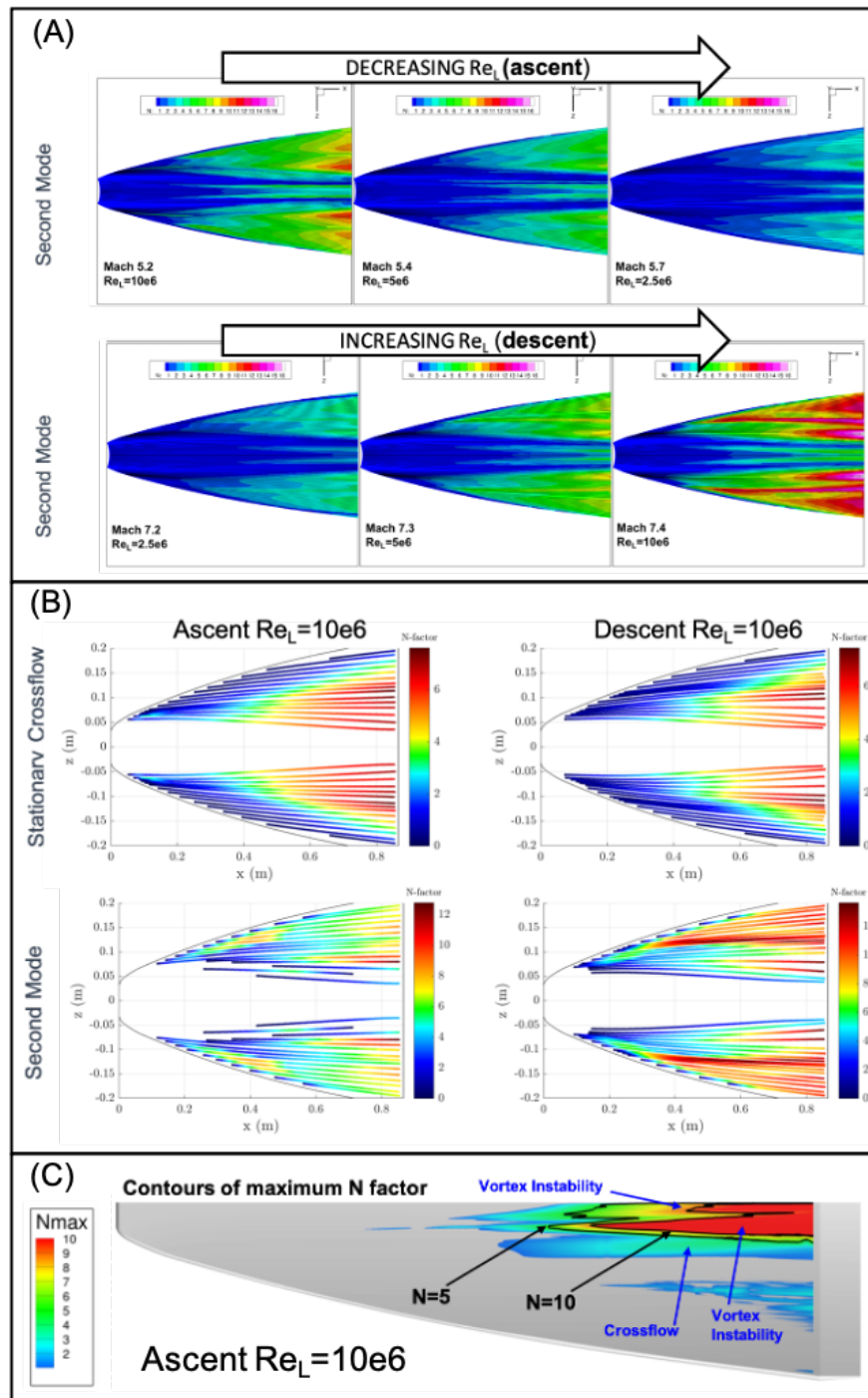


Figure 17. Computed boundary layer stability maximum N-factors for BOLT nominal trajectory conditions conducted by (A) APL using LASTRAC, (B) TAMU using EPIC, and (C) Sandia National Laboratory using BiGlobal analysis.

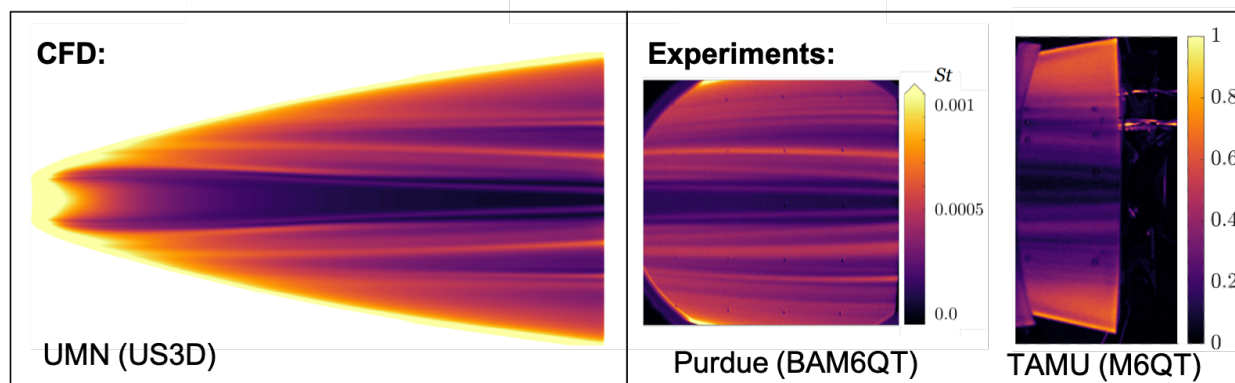


Figure 18. Surface contours of nondimensional surface heat flux.

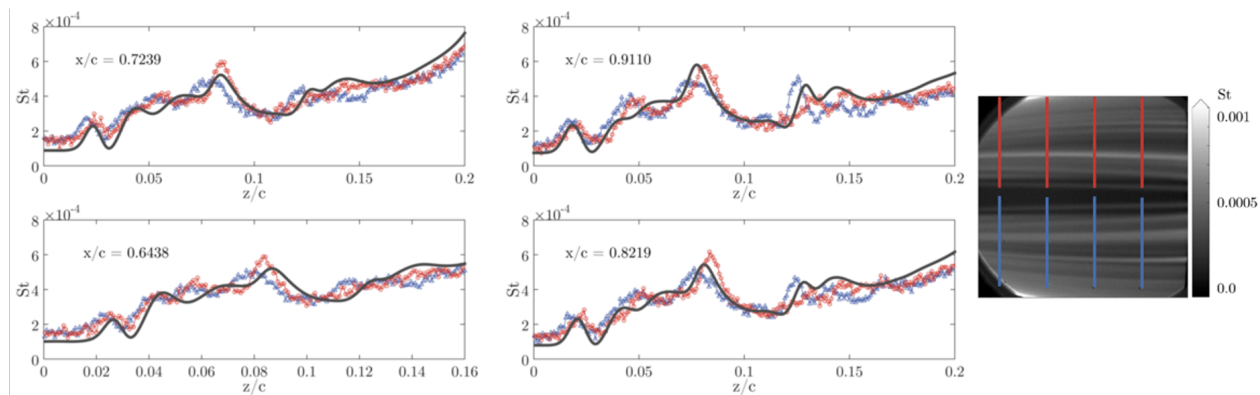


Figure 19. Line plots of nondimensional surface heat flux. Blue and red symbols correspond to IR measurements at Purdue. Solid black line corresponds to US3D computations.

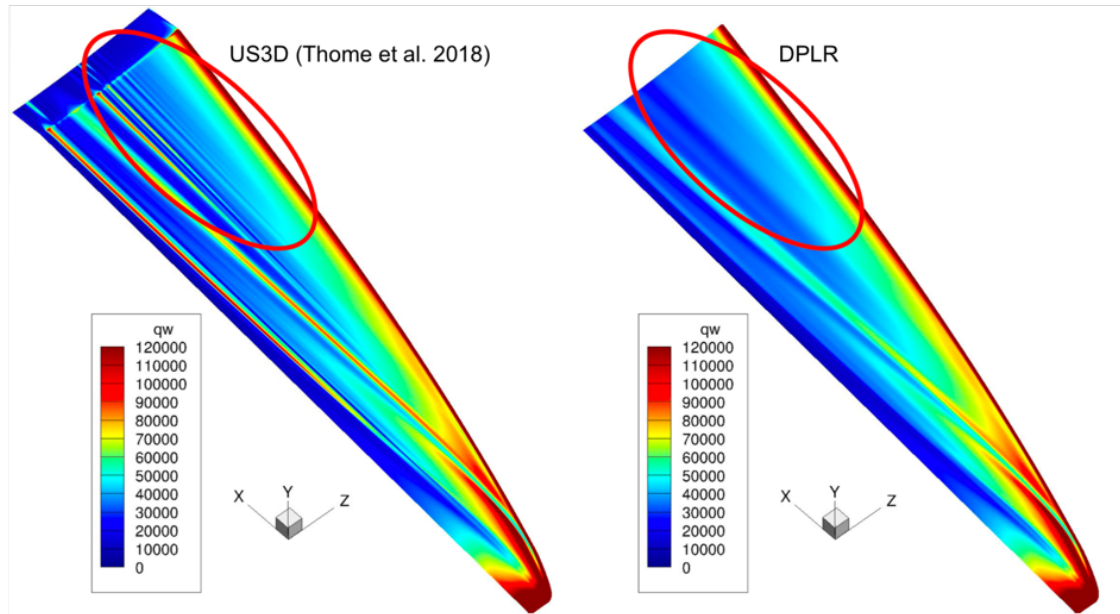


Figure 20. Surface heat flux comparison between low-dissipation (US3D) and standard (DPLR) numerics

where the streaks are seen under quiet flow, suggesting that these streaks are due to the stationary crossflow instability perhaps seeded by the vorticity from the blunted nosetip.

7. Plan to Make Data Available to AFOSR

As part of the grant deliverables, APL was tasked to make a plan to share the data from the entire BOLT program with AFOSR such that it could be made available to other researchers. A significant amount of data were generated by the research performed by APL and the BOLT team during this grant, consisting of computational as well as ground and flight test data. APL has created a share folder on the "Box" service to house a final data package that will attempt to include all the relevant data and records from the program. This Box share drive "BOLT Deliverables to AFOSR" has been shared with the Program Officer, Dr. Popkin.

APL will also provide AFOSR with a hard drive containing a copy of the Box folder at the conclusion of this grant.

Finally, APL and AFOSR are in discussions with the Hypersonic Vehicle Simulation Institute (HVSII), sponsored by the Department of Defense High Performance Computing Modernization Program, for potential archiving of the BOLT data.

8. List of Publications

This section summarizes the conference papers and publications known to the APL authors of this report from the entire extended BOLT team during the period of performance of this grant. This project was led by APL but the research and datasets generated from the ground testing and analyses in the APL grant were utilized by the broad team for these publications. Publications with APL lead authors are highlighted bold.

- **Wheaton, B. M., Berridge, D. C., Wolf, T. D., Araya, D. B., Stevens, R. T., McGrath, B. E., Kemp, B. L., & Adamczak, D. W. (2021). Final Design of the Boundary Layer Transition (BOLT) Flight Experiment. *Journal of Spacecraft and Rockets*, 58(1), 6–17. <https://doi.org/10.2514/1.A34809>**
- Leyva, I. A., & Cummings, R. M. (2021). Introduction to the Special Section on the Boundary Layer Transition (BOLT) Flight Experiment. *Journal of Spacecraft and Rockets*, 58(1), 4–5. <https://doi.org/10.2514/1.A34872>
- Berry, S. A., Wheaton, B. M., & Chynoweth, B. C. (2021). Secondary Side Considerations for Boundary Layer Transition Flight Experiment. *Journal of Spacecraft and Rockets*, 58(1), 18–25. <https://doi.org/10.2514/1.A34778>
- Hoerschgen-Eggers, M., Kirchhartz, R. M., Jung, W., Schoppmann, K., Ettl, J., & Wittkamp, M. (2021). Boundary Layer Transit Flight Experiment: Mission Overview, Launch Vehicle and Payload Subsystems. *Journal of Spacecraft and Rockets*, 58(1), 26–37. <https://doi.org/10.2514/1.A34877>
- Rieken, E. F., Berry, S. A., Mason, M. L., & Greene, F. A. (2021). Aerothermodynamic Ground Tests in Support of the Boundary Layer Transition Flight Experiment. *Journal of Spacecraft and Rockets*, 58(1), 38–53. <https://doi.org/10.2514/1.A34803>
- McKiernan, G. R., Chynoweth, B. C., Schneider, S. P., Berridge, D. C., & Wheaton, B. M. (2021). Boundary Layer Transition Preflight Experiments in a Mach-6 Quiet Tunnel. *Journal of Spacecraft and Rockets*, 58(1), 54–66. <https://doi.org/10.2514/1.A34772>
- Kostak, H. E., & Bowersox, R. D. W. (2021). Preflight Ground Test Analyses of the Boundary Layer Transition (BOLT) Flight Geometry. *Journal of Spacecraft and Rockets*, 58(1), 67–77. <https://doi.org/10.2514/1.A34858>
- Moyes, A. J., & Reed, H. L. (2021). Preflight Boundary-Layer Stability Analysis of BOLT Geometry. *Journal of Spacecraft and Rockets*, 58(1), 78–89. <https://doi.org/10.2514/1.A34792>
- Knutson, A. L., Thome, J. S., & Candler, G. V. (2021). Numerical Simulation of Instabilities in the Boundary-Layer Transition Experiment Flowfield. *Journal of Spacecraft and Rockets*, 58(1), 90–99. <https://doi.org/10.2514/1.A34599>
- Li, F., Choudhari, M. M., & Paredes, P. (2020, June 15). Streak Instability Analysis on BOLT Configuration. AIAA Paper 2020-3028. <https://doi.org/10.2514/6.2020-3028>

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- Mullen, C. D., & Reed, H. L. (2020, June 15). Linear Parabolized Stability Analysis of the BOLT Flight Geometry at Off-Nominal Conditions. AIAA Paper 2020-3027. <https://doi.org/10.2514/6.2020-3027>
 - **Wheaton, B. M., Berridge, D. C., Wolf, T. D., Araya, D. B., Stevens, R. T., McGrath, B. E., Kemp, B. L., & Adamczak, D. W. (2020). Final Design of the Boundary Layer Transition (BOLT) Flight Experiment. AIAA Paper 2020-1041. <https://doi.org/10.2514/6.2020-1041>**
 - Chynoweth, B. C., Schneider, S. P., Wheaton, B. M., & Wolf, T. D. (2020). Transition Measurements with Forward and Aft Facing Steps on the BOLT Geometry at Mach 6. AIAA Paper 2020-1560. <https://doi.org/10.2514/6.2020-1560>
 - Rieken, E., Berry, S. A., Broslawski, C., & Greene, F. (2020). Aeroheating Measurements of BOLT Aerodynamic Fairings and Transition Module. AIAA Paper 2020-1561. <https://doi.org/10.2514/6.2020-1561>
 - Kostak, H., & Bowersox, R. D. (2020). Hypersonic Boundary Layer Off-Body and Surface Measurements on the AFOSR BOLT Geometry. AIAA Paper 2020-1043. <https://doi.org/10.2514/6.2020-1043>
 - Thome, J., Reinert, J., & Candler, G. (2020). Effect of Steady Forcing on BoLT Flow-field for Flight Reynolds Numbers. AIAA Paper 2020-1042. <https://doi.org/10.2514/6.2020-1042>
 - Berry, S. A., Wheaton, B. M., & Chynoweth, B. C. (2020). Secondary Side Considerations for BOLT Flight Experiment. AIAA Paper 2020-1559. <https://doi.org/10.2514/6.2020-1559>
 - Moyes, A., & Reed, H. L. (2019, June 17). Nonlinear Boundary-Layer Stability Analysis of BOLT and HiFiRE-5. AIAA Paper 2019-2972. <https://doi.org/10.2514/6.2019-2972>
 - Mullen, C. D., Moyes, A., Kocian, T. S., & Reed, H. L. (2019). Heat Transfer and Boundary-Layer Stability Analysis of Subscale BOLT and the Fin Cone. AIAA Paper 2019-3081, June. <https://doi.org/10.2514/6.2019-3081>
 - Thome, J., Knutson, A., & Candler, G. V. (2019). Boundary layer instabilities on BoLT subscale geometry. AIAA Paper 2019-0092. <https://doi.org/10.2514/6.2019-0092> Berry, S. A., Mason, M. L., Greene, F., King, R., Rieken, E., & Basore, K. (2019). LaRC Aerothermodynamic Ground Tests in Support of BOLT Flight Experiment. AIAA Paper 2019-0091. <https://doi.org/10.2514/6.2019-0091>
 - Cook, D. A., Thome, J., Nichols, J. W., & Candler, G. V. (2019). Receptivity analysis of BOLT to distributed surface roughness using input-output analysis. AIAA Paper 2019-0089. <https://doi.org/10.2514/6.2019-0089>
 - Kostak, H., Bowersox, R., McKiernan, G. R., Thome, J., Candler, G. V., & King, R. A. (2019). Freestream Disturbance Effects on Boundary Layer Instability and Transition
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on the AFOSR BOLT Geometry. AIAA Paper 2019-0088. <https://doi.org/10.2514/6.2019-0088>

- **Berridge, D. C., Kostak, H., McKiernan, G., Wheaton, B. M., Wolf, T. D., & Schneider, S. P. (2019, January 7). Hypersonic Ground Tests With High-Frequency Instrumentation In Support of the Boundary Layer Transition (BOLT) Flight Experiment. AIAA Paper 2019-0090. <https://doi.org/10.2514/6.2019-0090>**
- Kimmel, R. L., Adamczak, D., Borg, M. P., Jewell, J. S., Juliano, T. J., Stanfield, S., & Berger, K. (2018). HIFiRE-1 and -5 flight and ground tests. AIAA Paper 2018-0056. <https://doi.org/10.2514/6.2018-0056>
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9. Summary

The Boundary Layer Transition (BOLT) experiment represents an evolution in basic science flight testing for hypersonics. From the inception of the flight experiment design, academia was partnered with a university affiliated research center, government, industry, and international partners. Together, this diverse team worked rapidly in close coordination to develop and execute a sounding rocket flight test intended to gather boundary-layer transition data on a complex geometry in the flight environment. Although the flight test ultimately did not achieve the desired experimental conditions, the Boundary Layer Transition research resulted in new experimental databases, new computational tool development for complicated hypersonic flows, and significant new workforce development through the inclusion of students in the program.

A project like BOLT fits within APL's core purpose as a University Affiliated Research Center (UARC), in the organization of collaborative activities that promote linkages between the DoD, academia, and industry. APL served a key role in fostering education and providing mentorship to the students who were deeply involved in the unique project from the onset. Several of the BOLT graduate student researchers worked as summer interns alongside staff at APL to help solve

critical challenges in the design of the flight experiment. These students were exposed to fast-paced, schedule-driven research that aimed to accomplish a complex objective (hypersonic flight test).

Pairing academia with a UARC to execute BOLT was beneficial to both parties. APL staff were able to learn from top researchers via the collaborative relationship with the University of Minnesota, Purdue University, and Texas A&M University. These researchers brought advanced testing and simulation capabilities to apply to BOLT, capabilities that APL staff subject matter experts are now able to apply to other hypersonic programs. BOLT serves as a potential new model for accelerating transition of capabilities, not just in boundary-layer transition, but in other technical disciplines that remain a challenge to successfully field new hypersonic systems.

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A. Detailed Status Bullets from Kickoff to Flight

This appendix contains the detailed regular status update bullets communicated by APL from the grant kickoff until the day of flight, including a detailed day-by-day breakdown of the BOLT flight campaign at Esrange Space Center.

9/8/2017 through 9/22/2017

- Upcoming dates/milestones:
 - October 9th - attempt to freeze geometry
 - 10/23-10/27 - blockage test at Purdue University, potential to delay one week based on tunnel schedule as of now
 - October/November? - APL visit to AFRL/GHI
- Major activities involve attempting to down-select between the 2.5-mm and 5-mm geometries... which will involve quick looks at thermal and also transition differences between the two. The decision will need to be made soon. Potential need for fairing the aft portions of the geometry is needed to reduce aft-facing base area, and will be explored by Minnesota and by APL.
- A quick look thermal analysis was performed by JHU/APL on both the 2.5-mm and 5-mm geometries, using trajectory provided by Dave Adamczak. The preliminary results show that both geometries look to be survivable with a TZM nosetip. The effect of LE radius on peak stagnation point temperatures during ascent phase was small. The results indicate that thermal survivability will not be a huge driver in the decision to down-select to a particular LE radius.
- CFD/Stability
 - A LINK3D grid has been created for the 5-mm geometry and a checkout laminar mean flow has been completed using CFD++ at full scale flight conditions.
 - The initial laminar mean flow was run at Mach 7.4 $Re=10e6$, and flow features compare qualitatively with CFD results presented by UMN at the kickoff.
 - Additional mean flows are running now at $Re=2.5e6$ and $5e6$ descent phase
 - Updated LSTRAC conversion scripts to fix some bugs specific to the BOLT geometry, and initial stability results should be running soon, at least for the second-mode instability
- Ground Testing
 - JHU/APL is working with Purdue to schedule a blockage test, perhaps as soon as late October, to size the subscale model. Purdue is booked in November and may shut down for a nozzle swap in December.
 - Besides fixing the geometry, JHU/APL is working to choose material for the model. The options are Nylon/TSP or PEEK/IR, with the decision to be balanced against material availability, cost, fabrication schedule, and also the availability of IR camera for the test.
 - Ordered 12 Kulite A-screen sensors, with a quoted lead time of 20-22 weeks, which puts delivery into mid-February.
- Flight Testing
 - Hosted Doug Dolvin at JHU/APL for meeting to discuss AFRL/APL coordination
 - Briefed by Dave Adamczak via telecon on status of AFRL hardware design and integration planning
 - Working to schedule trip to AFRL to meeting with Dave and others re: HIFIRE program, and potentially to tour GHI.

9/23/2017 through 9/28/2017

- Upcoming dates/milestones:
 - October 9th - attempt to freeze geometry
 - 10/23-10/27 - blockage test at Purdue University, appears on track
 - 10/26-10/27 - APL visit to AFRL/GHI, need to confirm dates
- Established BOLT Mailing List
- Flight Geometry
 - APL and UMN are exploring methods to add fairings at the aft end of the Flight Geometry to avoid transonic buffeting due to separated flow there. APL Aerodynamics SME reviewed unfaired design and recommended a 30 degree fairing.
 - Added versioning control and change log to SharePoint to track different Flight Geometry versions
 - Exploring preliminary subtle changes to the side gullies to improve waviness and to ensure true round radius on the swept leading edges, without affecting the existing concave surfaces and flow field.
- CFD/Stability
 - Created 2nd structured grid on the 2.5-mm geometry, using existing topology from 5-mm geometry
 - Completed laminar mean flows and second-mode stability calculations on both 2.5-mm and 5-mm geometries (B025-100 and B050-100)
 - Ascent phase, Mach ~5.4, Re = 2.5e6, 5e6, and 10e6
 - Descent phase, Mach ~7.4, Re = 2.5e6, 5e6, and 10e6
 - Ran angle of attack (4 deg) and yawed (4 deg) cases at descent phase Re=5e6, representing worst case AoA/yaw for a descent experiment. Examined edge and near-wall streamlines to verify that flow from side gullies would not be expected to contaminate the concave surfaces. Thus far, it appears the design is significantly robust to contamination effects at 4-deg AoA and yaw.
 - Ran CFD and BL stability at Purdue tunnel conditions for a notional 33.3% subscale model, to be used for blockage estimates needed for model sizing.
- Ground Testing
 - Worked to design a blockage test of two rapid-prototype models to be conducted 10/23-10/27 at Purdue.
 - Model scales chosen as 0.333 and 0.290 based on analysis of the BOLT CFD flow field compared to the HIFiRE-5 scale model that has been used in previous experiments at Purdue. Details have been posted in slides on the SharePoint.
 - Coordinated with Purdue to accommodate installation interface details, coordinate application of the TSP by Greg McKiernan, and discuss instrumentation.

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- Conceptual and final mechanical design of (2) blockage models (materials, structural, thermal and facility interface considerations). Models to be designed with metallic nosetip and nylon main body. Models will contain Kulites to verify local surface pressure at each orientation to ensure the tunnel started. One PCB is also planned to be placed based on preliminary stability analyses.
 - Structural analysis of 3D-printed blockage model indicates sufficient margins for both Polycarbonate and Nylon materials. Nylon was chosen due to uncertainties in adherence of the temperature-sensitive paint to the polycarbonate material.... Nylon has been used historically at Purdue for TSP.

9/29/2017 through 10/6/2017

- Upcoming dates/milestones:
 - 10/6 - Telecon held to review leading-edge radius choice
 - 10/16 - last target date for blockage models to arrive at Purdue for application of sensors and TSP
 - 10/23-10/27 - blockage test at Purdue University
 - 10/26-10/27 - APL visit to AFRL/GHI
- Finalizing Leading Edge Radius
 - Telecon held Friday 10/6 to review analyses to support choice of 5-mm geometry as final radius.
 - Telecon attendees: APL (Wheaton/Berridge/Wolf/D'Alessio), AFOSR (Leyva), WPAFB (Adamczak/Dolvin/Kimmel/Borg/Johnston), CUBRC (Wadhams/Holden), TAMU (Reed/Moyes/Kocian/Kostak), Purdue (Schneider/Chynoweth/McKiernan), Minnesota (Candler/Thome), VirtusAero (Johnson), NASA (Berry)
 - All attendees in agreement to proceed forward with 5-mm leading edge based on:
 - Available thermal, CFD, and stability data from APL/Minnesota do not indicate major differences between the two leading-edge radii
 - 5-mm radius offers improved internal volume for instrumentation
 - 5-mm radius reduces thermal stresses on swept leading edge
 - 5-mm radius flow contamination appears robust to AoA/yaw based on limited analyses
 - Concern expressed by Roger Kimmel and others above flat portion of leading edge, particularly at yawed conditions. Does it introduce undesirable flow features? APL took action to review existing 4-deg yaw CFD case in more detail. Previously APL had just looked at surface heat transfer.
 - Some discussion on multiple "lobes" of N-factors on stability analyses presented by APL.
 - Now that final LE radius is chosen, we can finalize finer details of design to lock it down for Purdue test and conceptual flight geometry design.
- Flight Geometry

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- APL completed proposed new 5-mm geometry (B050-110) which modifies side gutter features to reduce waviness and increase volume near leading edge. CAD files uploaded to SharePoint for potential evaluation by Minnesota and others.
 - APL completed aerodynamic fairing concept and sent CAD to AFRL/RQ for evaluation of aerodynamic stability with CART3D. The first concept does not violate any existing BOLT Flight Geometry.
 - CFD/Stability
 - VirtusAero LLC is now under contract and will be starting work soon, pending scheduling of kickoff telecon
 - APL completed quick look review of all CFD and stability data to date in order to present at 2.5-mm vs. 5-mm design decision telecon on 10/6.
 - Upcoming work to evaluate B050-110 side gutter design change in CFD to verify attachment line streamlines remain largely unchanged, and no adverse effects on main surface.
 - Ground Testing
 - Continued coordination with Purdue to plan blockage test
 - Finalized design on two blockage models. Nylon was not available in a light color (only black) which would have hindered potential TSP signal. Based on material availability the models will be 3D printed in a bright white polycarbonate instead. 3D printing was chosen as a low-cost option that could be manufactured quickly in order to complete the blockage test as soon as feasible.
 - Began fabrication on two rapid-prototype blockage models (29.0% and 33.3% scales)
 - 3D printed several material evaluation coupons and sent to Purdue to be painted with TSP. The coupons will be tested in the tunnel to determine the ability of TSP to adhere to the new material (polycarbonate), which has never been used with TSP at Purdue. The results will impact whether or not the models can be painted with TSP.

10/7/2017 through 10/12/2017

- Upcoming dates/milestones
 - 10/16 - blockage models to arrive at Purdue for application of sensors and TSP
 - 10/23-10/27 - blockage test at Purdue University
 - 10/26-10/27 - APL visit to AFRL/GHI
- Main efforts this week have been to understand impacts of side gutter design change in the B050-110 version geometry and completing fabrication of Purdue blockage models
- Concerns about a potential transitional area on the side gutter, just below the aft portion of the swept leading edge.
 - Present in both B050-100 and B050-110 geometries, although it appears B050-110 may reduce the effect slightly (based on APL quick look CFD)

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- This region may be susceptible to transition due to spillover flow from the high-pressure concave surface. Indicated by presence of vortex structure, increased Re_{θ}/M_e from the thickened boundary layer, and also seen in Minnesota DNS video presented at kickoff.
 - The main concern would be transition near the leading edge on the side gutter spreading to contaminate the attachment line transition experiment.
 - Minnesota is currently investigating the B050-110 geometry with high-order CFD to see if the new geometry reduces the potential for transition in that region. If the trend indicates transitional flow is reduced, another design iteration may be warranted to increase thickening of the side gutter even more (if no adverse effects at yaw/angle-of-attack are indicated).
 - Flight Geometry
 - Further Flight Geometry and aerodynamic fairing design iterations on standby pending CFD analyses of B050-110 geometry and AFRL CART3D results of the aerodynamic fairing concept
 - CFD/Stability
 - Created new grid of B050-110 geometry using same topology from previous B050-100 grid
 - Re-ran all CFD cases with new B050-110 geometry including the angle-of-attack and yaw, but have not yet fully analyzed the results. A quick look thus far indicates very similar flow on the concave surfaces to the B050-100.
 - Ground Testing
 - Completed fabrication on two rapid-prototype blockage models (29.0% and 33.3% scales) expected Friday 10/13, to arrive at Purdue on Monday 10/16
 - Some images of blockage models during fabrication posted [on SharePoint](#)
 - Purdue completed painting of polycarbonate coupons with TSP to test adherence, and coupons were due to be installed in the tunnel to be cycled through a few runs late this week

10/13/2017 through 10/20/2017

- Upcoming dates/milestones
 - 10/23-10/27 - blockage test at Purdue University
 - 10/26-10/27 - APL visit to AFRL/GHI
 - November - interface meeting with launch provider (planned)
- The B050-110 is still being vetted as the candidate final geometry. All CFD results to date indicate no significant flowfield changes on the attachment line or concave surfaces. CFD indicates that B050-110 may reduce spillover flow near the leading edge within the side gutter which has the potential to transition and contaminate attachment line measurements.

University of Minnesota is working to verify side gutter transition near leading edge is reduced in the B050-110, without other adverse effects.

- Working with Ivett and AFRL/RQ to plan interface meeting with launch provider
- Flight Geometry Design
 - On standby pending CFD analyses of B050-110 geometry and AFRL CART3D results of the aerodynamic fairing concept.
 - At this point the schedule will likely not allow further design tweaks of the main Flight Geometry so we will likely have to proceed with the B050-110 unless new results indicate problems.
- CFD/Stability
 - VirtusAero LLC is now under subaward contract to begin analyzing the BOLT geometry with STABL-3D. Held kickoff telecon with Heath Johnson and provided him with a mean flow of the B050-110 at flight conditions to use as a test case for setting up his stability analysis methods.
 - APL compared CFD of new B050-110 geometry to previous B050-100 results
 - Re_{θ}/M_e is lowered in the side gutter region directly underneath the leading edge, indicating the potential for reduced transitional flow impacting the leading edge. However, Re_{θ}/M_e does appear slightly higher in the center of the gutter. We believe that the benefits of potential reduction in transitional flow near the leading edge outweigh the potential increased transition in the gutter centerline, where it is not expected to impact the main experiments.
 - Near-wall and edge streamlines appear to be same on the leading edge for all the cases examined thus far
 - 2nd mode BL stability results were compared between the -100 and -110 for one case and appeared unchanged
 - University of Minnesota is running high-order CFD of the B050-110 which should indicate how the side gutter design may impact transition
- Ground Testing
 - Blockage test at Purdue remains on track to start Monday 10/23
 - Blockage models arrived at Purdue on Monday 10/16
 - Purdue testing 3D-printed polycarbonate (PC) coupons provided by APL which indicated that temperature-sensitive paint will likely not adhere to the material. The coupons bubbled after only a few runs in the tunnel per e-mail from Greg McKiernan on Tuesday 10/17. Removal of the TSP from the model in case of bubbling was also a concern, as the PC plastic could be damaged by solvents. The decision was made to forego the TSP.

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- In lieu of TSP, IR images of the models will be attempted to try to obtain qualitative transition data during the blockage testing. Purdue was able to coordinate borrowing Matt Borg's IR camera for next week's test.
 - Purdue is finishing installation of instrumentation of the blockage models (2 Kulites and 1 PCB on each) and is applying registration markings to the models
 - APL generated CART3D inviscid CFD results for a matrix of total angle of attack and model roll angle, and extracted surface pressure ratios (p/p_{∞}) at the Kulite sensor locations. The data will be used on the fly to verify that the tunnel has started at different model orientations.

10/21/2017 through 10/27/2017

- Upcoming dates/milestones:
 - TBD - telecon to finalize geometry
 - TBD - telecon to review ground test data
 - November 10 - interface meeting with launch provider
- Flight Geometry Design
 - APL/AFRL held meeting at WPAFB 10/26-10/27 to review HIFiRE design details, discuss current design status, tour integration and structural/environmental test facilities, and to visit GoHypersonic Inc. This meeting served as a "kickoff" for conceptual design of the Flight Geometry.
 - APL seeks to schedule a telecon to finalize geometry, e-mail will be sent early next week to schedule. Desired telecon date no later than 11/7.
 - Conceptual design of flight geometry will commence shortly after decision to finalize geometry (B050-110 is current version). Conceptual design will begin with the following high-priority studies:
 - Assessment of number of Sensor Collection Boards capable of fitting within the internal volume of BOLT, which will then drive the number of allowable sensors to be fixed. APL will need to freeze the number and types of sensors early in order to allow detailed electronics/telemetry concepts to be finalized.
 - More thermal analyses are needed on the final 3D geometry to narrow down materials selections. Current plan is for TZM/SS/Aluminum like in previous HIFiRE designs, but the leading edges may need to be Stainless Steel due to heating concerns. Materials will also drive weight, which is needed for aerodynamic stability and stack performance estimates.
 - AFRL/RQ completed CART3D analysis of aerodynamic fairing concept #1. The fairing, even though short, reduced estimated static margin by 10%. The benefits of adding a fairing versus flying with aft-exposed area will continue to be weighed by APL, AFRL, and also the launch services provider who will ultimately be the one driving the

requirement. The fairing issue currently remains open but should not impact Flight Geometry design freeze at this time.

- CFD/Stability
 - University of Minnesota continues efforts to simulated B050-110 design to assess gutter change impacts on transition
- Ground Testing
 - Completed blockage testing at Purdue Mach-6 Quiet Tunnel:
 - The 0.333 scale model started at 0 degrees and +/-4 degree AoA and yaw under quiet flow, which were the target limits. Model starting was indicated by tunnel wall Kulite and hot film, and by static pressure readings from Kulites on the model.
 - IR imaging was obtained of the 0.333 scale model under quiet and noisy flow.
 - Transition was NOT observed under quiet conditions at the current ~130-135 psia maximum quiet pressure. A variety of streamwise streaks, presumably from the relatively high roughness of the blockage model, were visible in the IR images. These streaks seemed to remain laminar at 0-deg and 4-deg conditions.
 - Under noisy conditions the model was fully turbulent at the aft of the geometry, even at low Reynolds numbers (45 psia and below).
 - Texas A&M is completing testing in the TAMU M6QT and ACE tunnels and shared some IR imaging videos.
 - APL plans to immediately begin design of the "final" Purdue model at 0.333 scale, with the hopes of obtaining new flow visualization images on the smoother model to assist with instrumentation placement.

10/29/2017 through 11/3/2017

- Upcoming dates/milestones:
 - November 10-16 - interface meeting with launch provider
 - TBD - telecon to finalize geometry
 - TBD - telecon to review ground test data
- APL submitted two AIAA Abstracts for AVIATION 2018
 - "Boundary Layer Transition (BOLT) Flight Experiment Design" to summarize flight hardware design and estimates of transition in flight. Final paper to include AFRL/RQ as co-authors.
 - "Experiments in a Hypersonic Wind Tunnel In Support of the Boundary Layer Transition (BOLT) Flight Experiment" with Purdue as co-authors. The final paper could include results from other tunnels (i.e. Langley) if desired.
- Flight Geometry Design

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- We are proceeding for now with the B050-110 geometry. A telecon to summarize analyses performed on the design will slip until sometime after 11/16 following the launch provider interface meeting.
 - APL team is reviewing notes and materials from AFRL/RQ on HIFiRE mechanical details
 - Beginning conceptual mechanical design of Flight Geometry hardware
 - Initial goal is assessment of number of Sensor Collection boards within available internal volume
 - Exploring concepts for assembly of Flight Geometry to minimize fasteners in regions of interest, and to (if possible) avoid dissimilar materials in regions where steps/gaps from thermal expansion would affect the experiments
 - APL is planning a 3D conceptual analysis of the Flight Geometry to determine available materials to meet thermal survivability. It is unknown whether the swept leading edges can be made with aluminum, or if stainless steel is needed.
 - Still tracking potential need for aerodynamic fairing on BOLT as an open issue.
 - CFD/Stability
 - Minnesota shared some new preliminary high-order CFD results of the B050-110 geometry. The results showed streamwise streaks on the main surface, which have been observed in the Purdue quiet flow tests. The results confirmed that the B050-110 slightly reduces the spillover flow on the gutter region, but does show that the spillover flow remains potentially unstable to transition.
 - APL is continuing to analyze stability of the main concave surface using LASTRAC. Attempts are being made to analyze the effect of disturbance path choice on the results. Stationary crossflow analyses are also currently being attempted.
 - Beginning to look at CART3D inviscid pressure mappings of BOLT as a function of angle of attack and roll angle, in order to find regions of the geometry that are most sensitive to vehicle orientation. These analyses will identify optimal regions to obtain mean pressure measurements in flight for analyzing angle of attack and yaw angle.
 - Ground Testing
 - Beginning conceptual planning of final Purdue model, including roughness experiments
 - Analyzing results from Purdue blockage testing
 - Purdue blockage testing results will be documented in a PowerPoint presentation and made available on SharePoint
 - APL has asked if Purdue might be able to modify one of the blockage test models to add 1-2 high-speed pressure sensors within the gutter region and repeat the quiet flow case. This measurement may help confirm if the gutter region is transitioning before the main surface, especially near the leading edge from the spillover flow.
 - Ordered 12 PCB132B sensors
 - NASA Langley
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- APL and NASA are working to establish a "Space Act Agreement." The draft agreement was written and provided to APL contracts.

11/4/2017 through 11/11/2017

- Upcoming dates/milestones:
 - 11/10 - Meeting with DLR MORABA
 - TBD - telecon to finalize geometry
 - TBD - telecon to review ground test data
- Launch Services Provider discussion held 11/10 at DLR Oberpfaffenhofen
 - DLR MORABA has been selected as the launch provider for BOLT, but is not yet under contract.
 - Current planned stack is S-31/Improved Orion
 - Discussion of potential test ranges for BOLT was held. Selection of range should ideally be done soon (~2 months) in order to lock down a specific target date to drive schedule.
 - Woomera is not a likely test range due to a planned shutdown in 2019/2020.
 - Andoya Norway is a top candidate range due to a fairly flexible schedule, familiarity with the range by MORABA, and ocean testing allows a good variety of downrange trajectories. The downside is that recovery of the test article is not likely.
 - Esrange Sweden could be an alternate choice, but has some restrictions on downrange for flight over land.
 - Exploring option to fully de-spin near apogee for the turn over maneuver using a DLR MORABA yo-yo system as opposed to the "bang bang" maneuver.
 - Discussed static margin and aerodynamic fairing options with MORABA. Continuing to assess need for aerodynamic fairing. If the stack length changes due to different turn over maneuver hardware, it could decrease the length and improve the static margin to allow a more gradual fairing.
- Flight Geometry Design
 - Conceptual design of BOLT Flight Geometry is underway
 - More thermal analyses are underway to identify candidate material selections
- CFD/Stability
 - APL is making progress in debugging stationary crossflow stability results using LASTRAC, to supplement the existing second-mode LST results at flight conditions. The LASTRAC spanwise growth rate optimizer is having difficulties with the BOLT mean flow and thus the approach has switched to testing a matrix of spanwise wavenumbers instead. Preliminary results have been obtained at flight conditions but need further analysis.
 - CART-3D matrix at Mach 6 is being used to identify areas of BOLT most sensitive to changes in mean pressure with vehicle orientation. Study in progress.
- Ground Testing

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- APL has decided to send funding to CUBRC for fabrication of a full-scale model and some preliminary runs in LENS, because APL can get CUBRC the funding the fastest to get them started.
 - Quick look powerpoint [slides](#) from APL/Purdue Blockage Test have been posted to SharePoint
 - Telecon to be scheduled to discuss all existing APL/TAMU ground test data and future ground testing plans
 - Conceptual planning of final subscale model for Purdue/Langley is underway

11/12/2017 through 11/22/2017

- Program
 - Ivett Leyva established bi-weekly recurring telecon for BOLT PI's to discuss program status
- Flight Experiment
 - Dave Adamczak presented analyses on various flight test range options. Minimal impact of test range on expected Mach/Reynolds numbers during flight. Esrange Sweden appears to be most viable candidate going forward due to potential to recover the hardware.
- Flight Geometry Design
 - Conceptual design of BOLT Flight Geometry is underway
 - More thermal analyses are underway to identify candidate material selections
 - The good news --> BOLT appears to have more than sufficient internal volume to fit the number of circuit boards needed for the baseline APL instrumentation list (16 boards).
 - The not so good news --> Weight appears to be a challenge for BOLT, even with the assumption of aluminum leading edges. BOLT has approximately 1.7X the surface area of the HIFiRE-5B elliptic cone. Assuming a similar thickness of the outer mold line shell and similar materials, the weight would also be approximately 1.7X that of HIFiRE-5B. We can make design decisions to reduce weight, and some additional weight may be available from the re-orientation maneuver hardware change.
- Ground Testing
 - Dennis Berridge held telecon on 11/13 to discuss Purdue blockage test and gather model design inputs for final Purdue model
 - Attendees: Purdue, NASA (Berry), Matt Borg, Heather/Reed/Bowersox
 - Discussion of path forward for design of final subscale model for Purdue
 - Forward and backward facing steps identified as important candidate for roughness experiments. The question is how to integrate into this particular model without excessive complexity.
 - APL is moving forward with plan to fund CUBRC for a quick look test in the January/February timeframe

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- Held multiple calls with CUBRC to communicate goals of the experiment and plan a notional test matrix.
 - GOALS for CUBRC test:
 - Verify transition achieved on main surface near or at end of flight with TSP and sensors
 - Assess performance of side gutter
 - Assess main surface transition and side gutter isolation of transition at small angle of attack and small yaw angle
 - Use thin-film gauges to instrument all four leading edges and measure natural/tripped attachment lines
 - Place select PCB sensors to measure second-mode amplitudes based on LST calculations to be provided by APL
 - Ascent phase Mach numbers near 5 and 6 will be achievable with fully duplicated freestream conditions.
 - Descent phase Mach numbers (7-7.5), for moderately high Reynolds numbers, will not be duplicated freestream conditions due to exceeding total pressure limits. These conditions will have to be simulated Mach/Re tests.
 - Will need to work to move money to CUBRC for these tests quickly. Awaiting description of proposed work from CUBRC to initiate funding process.

11/23/2017 through 12/1/2017

- BOLT aerodynamics : Held meeting 11/29/2017 with APL Steering Committee (APLSC) aero experts to review fairing question and other aerodynamics questions
 - Attendees: Wheaton, Berridge, Rick Heisler, David Gers, Brad Marples, Trent Taylor, Ron Springer
 - Comments will be incorporated into upcoming master risk tracking spreadsheet, which will be created by APL to track potential issues
 - Reviewed AFRL/RQ static margin stability results with and without short fairing concept #1. Dave Adamczak provided new slides with static margin in terms of % body length.
 - CART3D results only available for two directions - lateral and longitudinal. APLSC recommended examining off-axis static margin to see if the "average" was a good approximation of true average.
 - With fairing, the worse case static margin during flight (longitudinal) was still above 5% body length. APLSC generally concurred that 5% body length is a sufficient accepted static margin by missile and sounding rocket community. The "average" static stability (average of lateral and longitudinal) is above 10% for the entire flight.
 - APLSC felt that CART3D doesn't do a great job of predicting pressure distributions behind shadowed or aft-facing region (like the leading edge). They recommended a further look with RANS to see how well pressure distribution and static margin matches.

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- Given CART3D limits in predicting shadowed regions. APLSC felt that the fairing/no-fairing differences in static margin could potentially be exaggerated by CART3D, or at least that the increment from the fairing may not be that accurate
 - Given the weight and complexity added by the relatively small fairing concept #1, and the potential that it would not help that much with separated flow, APLSC questions if it's better not to fly with a fairing at all.
 - BUT, concerns about impingement of separated flow onto the TSM/PSM creating unwanted heating or vibrations to the electronics or sensors (PCB's are sensitive to vibration in particular). Vibrations would be maximum at max-q, which is luckily a few seconds before the ascent transition window.
 - Concerns by APLSC about rotation rate (5 Hz) affecting science experiment via spillover from leading edge, or causing dynamic instability of some kind. The tangential velocity at the OML extreme for the Flight Geometry is ~ 8 m/s at 5 Hz, which is much lower than the freestream velocity. But RANS CFD case(s) should be performed with rotation rate simulated to examine flow field. Concern could be further mitigated by concentrating primary instrumentation on a side of the Flight Geometry main surface that is "windward" into the roll direction.
 - Flight Geometry Design
 - Regarding last week's bullet about BOLT having increased weight, it turns out Dave Adamczak has already been accounting for that in his analyses and estimates. Weight allowance for Flight Geometry is currently 51 kg. HF5B was 28 kg. Current BOLT concept, which does not include fastener, instrumentation, board, and other details, is at 42.5 kg.
 - Held meeting with thermal analysis team to spool up 3D analysis on concept. The first cut will be with correlations for heating, which may not be ideal for the leading edges, but a later round can include direct CFD heating inputs. Thermal analyses should be done on the first concept by mid- to late-December.
 - Ground Testing
 - Worked with CUBRC to identify nominal \$200K testing plan which includes model design/fab, 26 thin films, 7 PCB's, TSP, and a matrix of 7 runs in LENS II. Wrote SOW and procurement justification forms.
 - Initiated APL procurement process to fund CUBRC.
 - Reviewed initial CUBRC test matrix and provided proposed modified matrix to government team for review and discussion.
 - Completed initial concept design of modular Purdue subscale model. Revisions to design are now underway, along with instrumentation layout.
 - CFD/Stability
 - APL is re-running LASTRAC 2nd-mode N-factors with improved phase speed filtering to avoid a few spurious results.
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- LASTRAC LST results for 2nd-mode are being used to identify candidate sensor placement locations for the PCB's in flight and also to identify the expected second-mode frequencies (which could increase data sampling requirements from 2MHz to 3MHz if frequencies are present above the Nyquist frequency).
 - Two candidate BL edge streamlines have been identified. Working on set of slides documenting a proposed ascent phase PCB experiment with expected N-factors and frequencies to eventually be posted to SharePoint.
 - Discovered localized adverse pressure gradient near the swept leading edge that is causing locally high N-factors there. Unsure if N-factors are physical and working to analyze results.
 - APL modified post-processing scripts to calculate roughness tolerances for 40% PANT and input values of Re_k . Ran scripts on entire ascent and descent laminar CFD to identify tolerances for steps and also explore candidate roughness heights. Data are available but have not yet been fully analyzed.

12/2/2017 through 12/8/2017

- Upcoming dates/milestones:
 - 12/8/17 - Programmatic telecon @ 2pm ET
 - TBD - Purdue subscale model design telecon
 - TBD - CUBRC test concept telecon
 - 2/2/18: CoDR (one day, Washington DC area)
 - Week of 2/5/18 or 2/12/18 - potential Purdue entry #1
 - March 2018 - Purdue stainless steel throat install
- CoDR scheduling
 - Gathered input from BOLT team on availability for Conceptual Design Review in late January or early February in the Washington DC area.
 - Final date schedule to Friday 2/2/18. Ivett would like folks to plan on arriving for a group dinner the night before if possible.
- Flight Geometry Design
 - Thermal grid nearly completed for 3D thermal analyses to guide materials selections and thicknesses
- Ground Testing
 - CUBRC
 - Funding process in progress but not completed
 - APL completed slides proposing model concept for CUBRC test to identify high-priority areas for sensor access. To be sent to CUBRC and discussed further.
 - Following iteration on a test matrix and sensor layout with CUBRC, APL intends to call a telecon with the larger BOLT team to review plans and gather input.
 - Provided CUBRC with post-processed CFD data at flight conditions

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- Purdue
 - Greg McKiernan to perform a few runs with 3D printed model and instrumentation in the gutter region under quiet flow, probably before Christmas.
 - Purdue final subscale model concept underwent initial internal review at APL. Efforts are underway to define potential sensor locations so that internal design can accommodate sensors within those regions.
 - Mechanical design concept being revised following inputs from internal review, and iterated with APL machine shop to define cost and schedule estimates.
 - Purdue subscale model design will be briefed to Government Team and others before beginning fabrication, as the model is a BOLT deliverable. We would like to have that telecon soon to avoid holding up schedule. To be scheduled as soon as revised concept is completed.
 - Purdue plans to install the new stainless steel throat in March 2018. APL is weighing options for test entry dates around this install. The potential benefit would be increased quiet flow pressure. The potential risks are decreased quiet flow pressure, and schedule uncertainties and delays. The proposed path forward is to measure in February 2018 with the subscale model at current quiet pressures with the existing throat, then a follow on entry with the new throat to see if improved quiet pressure can be obtained.
 - NASA Langley
 - NASA technical team held internal meetings to provide inputs for completing their portion of the Space Act Agreement process.
 - Rudy King agreed to be POC for high frequency measurement entry at LaRC 20-Inch M6. Included Rudy on BOLT mailing list and SharePoint access.
 - CFD and BL Stability
 - Held telecon on 12/5/17 to review APL LASTRAC results. Slides are posted on SharePoint.
 - Attendees = TAMU (Reed/Saric/Bowersox/Kocian/Moyes/others), Borg, Kimmel, Candler, Thome, Heath Johnson, Leyva, Schneider, Scott Berry, Ryan Gosse
 - Covered LST results of ascent phase, including potential 2nd mode N-factors, considerations for placement of CUBRC and flight PCBs, and strange stability results near leading edge in potential adverse pressure gradient region.
 - Results provided to entire team for comment and further study
 - Planning to provide mean flow results to TAMU for stability analyses. Exchanged e-mails with Alex Moyes re: file formats needed to convert APL CFD++ mean flows to their format.

12/9/2017 through 12/15/2017

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- Upcoming dates/milestones:
 - 12/14/17 @ 2pm ET - Purdue subscale model design telecon (240-228-1000, #990272812)
 - TBD - CUBRC test concept telecon, pending newly iterated model concept
 - 12/22/17 - Programmatic telecon @ 11am ET
 - 2/2/18 - CoDR (full day, 900 Glebe Road, 2nd Floor, Arlington, VA 22203 ~~BRIC, 4075 Wilson Blvd Suite 350, Arlington, VA 22203~~)
 - 2/5/18-2/11/18 - Purdue subscale entry #1
 - 3/12/18-3/18/18 - tentative Purdue subscale entry #2
 - SharePoint multi-factor authentication began 12/12/17 to meet new DFARS regulations. Coordinated some login issues with some users and also shipped hard tokens to several users.
 - Flight Geometry Design
 - Thermal analyses experienced some minor grid format conversion problems but those appear to be corrected and the analyses are proceeding
 - Ground Testing
 - CUBRC
 - Provided CUBRC with slides proposing model concept, instrumentation location regions, and possible test conditions. Also posted those slides to SharePoint for government team input.
 - Held telecon with CUBRC last Friday 12/8 to discuss
 - Following telecon, CUBRC is working on response to APL RFQ that will include updated model concept with sensor locations based on APL feedback
 - Based on government bi-weekly telecon discussion, we will likely choose to reduce the AoA/beta angle from 4 degrees to 2 degrees, or potentially eliminate the AoA/beta cases entirely from the CUBRC matrix to test at more conditions and wall temperature ratios.
 - Some discussion in govt bi-weekly about making the CUBRC model "modular" to allow design changes or new features later. During initial discussions with Mike Holden at CUBRC we felt the complexity of a modular model design would offset the goals of trying to test the model as soon as possible.
 - CUBRC increased number of thin film gauges from 26 to 36 due to a miscommunication on the cost/scope. There will now be 10 PCB132's and 4 PCBM14's for mean pressure. New plan is higher instrumentation with 7 runs planned.
 - Received another model concept and TSP/instrumentation layout from Tim Wadhams on 12/14/17 and APL is reviewing
 - Purdue
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- Dennis Berridge held telecon with Schneider/McKiernan to review Purdue test plan and schedule entries.
 - Two entries targeted 2/5/18 and 3/12/18
 - Concern about Kulites on attachment line tripping flow. Found that simple Kulite installation on attachment line introduces roughness on the order of the boundary layer thickness. To mitigate, will test only one Kulite on one leading edge in first entry to compare against paste-on hot film measurements on a different leading edge. Kulite will be located on far downstream end of leading edge so tripping will not impact main surface. If Kulite roughness is too high the hole will be plugged for the second entry. Another option is to taper the hole to avoid the forward-facing step created by the kulite.
 - Discussion of microalignment of model to "true" zero AoA/beta, which would be good to design into the current sting adaptor. APL decided this type of system is not feasible for our budget and schedule. However, it would be possible for someone to build a different sting adaptor system to interface with this subscale model.
 - Prof. Schneider suggested goal of measuring streak locations to then measure under a given streak in the next test may not be feasible, since streaks are highly sensitive and may move between the two tests. We decided it's not required to measure directly under a streak for our test, but following with group of streaks is good enough.
 - Subscale model design
 - Completed next iteration of Purdue model concept (version D).
 - Slides documenting test plan and model concept posted to SharePoint
 - Set time for telecon with Purdue team next week to discuss final model design and subscale test schedule/design.
 - Ordered two blocks of Victrex PEEK from Boedeker plastics.
 - Machine shop requested a practice block to check techniques for working with PEEK. There is concern about the material warping from residual stresses.
 - Only outboard portions of the model have enough clearance from the model base to mount Kulites. We can introduce local cutouts to give enough space once instrument locations are determined. Need to determine actual Kulite clearance needed.
 - Purdue gutter testing on blockage model
 - Discussed gutter transition measurements on the blockage model with Greg. The test is this weekend.

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- Gutter transition test goal was set as finding whether the gutter transitions before the experiment surface. Nominal test matrix starts with max quiet, then moves to lower noisy pressures.
 - Purdue requested to have the model again this summer for their own follow-up testing.
 - Purdue suggested they may lend us PCB-132s for the instrumented test to instrument the gutter. Numbers TBD.
 - Requested to borrow IR camera from AFRL, it is available for the present schedule.
 - NASA Langley
 - Subscale model will need to be designed to NASA 20-Inch Mach-6 tunnel loads and within NASA safety guidelines. A stress analysis of the model is planned soon and buy-in from NASA safety head will be required prior to fabrication. Interfacing with Karen Berger to coordinate this approval so it does not hold up schedule for the Purdue test.
 - CFD/Stability
 - Provided grid, freestream conditions, LASTRAC results, and Tecplot mean flow sample to Alex Moyes at Texas A&M for independent comparison of stability results with EPIC
 - In general it is difficult to do code-to-code comparison with stability tools due to differences in codes, implementations, and inconsistent definition of marching paths
 - TAMU 2nd mode LPSE N-factors and frequencies showed good agreement in general with APL LASTRAC LST results for one streamline of one case (24.5s ascent condition).
 - TAMU plans to create completely independent higher-resolution grid and run the same flow conditions as APL
 - TAMU also plans to look at other mechanisms besides 2nd mode. Already some comparisons are being made to APL LASTRAC stationary crossflow results.
 - Packaging LASTRAC files to send to NASA Langley to help debug an issue with growth-rate optimized stationary crossflow N-factors.
 - Posted APL mean flow surface property files to SharePoint to enable comparisons by others to correlations, edge properties, etc.

12/16/2017 through 12/22/2017

- Upcoming dates/milestones:
 - 12/22/17 - CUBRC test concept / Programmatic telecon @ 11am ET
 - 12/22/17 - Target date to begin subscale model fabrication at APL
 - 2/2/18 - CoDR (full day, 900 Glebe Road, 2nd Floor, Arlington, VA 22203 ~~BRICC, 4075 Wilson Blvd Suite 350, Arlington, VA 22203~~). See

<https://community.apan.org/wg/afosr/w/researchareas/21795/2018-review-of-bolt-grant/> for more information (incorrect date currently displayed in image header)

- 2/12/18-2/18/18 - Purdue subscale entry #1 (postponed one week to add margin to manufacturing timeline)
- 3/12/18-3/18/18 - tentative Purdue subscale entry #2
- Flight Geometry Design
 - BOLT 3D thermal model is now running and post-processing is in progress
 - CFD heat flux files are being generated in FieldView format for comparison to the thermal model heat flux correlations to ensure that the correlations are correctly approximating expected heat loads. Currently, only laminar cases are available but the same conditions will be computed with turbulence modeling.
 - Initial comparisons to CFD show that thermal correlations appear to be underpredicting heat flux on the swept leading edges. Efforts are underway to use different correlations on leading edge and/or switch to purely CFD-based thermal inputs to the transient conduction code.
 - Despite the low heat flux inputs, preliminary results indicate that temperatures on aluminum swept leading edges may be higher than desired.
- Subscale model design and fabrication
 - APL Steering Committee (APLSC) held internal review of subscale model design and test plan, to complement external review telecons held with Purdue and the BOLT team last week. Reviewed existing load analyses. Requested additional meeting after first entry to review instrumentation layout for Entry #2.
 - Received NASA Langley 20-Inch Mach-6 loads from Karen Berger and performed loads analyses on model subscale concept. Provided model concept and loads analysis to NASA for review by Safety Head. APL requested concurrence to proceed with fabrication.
 - Fabrication of subscale model planned to commence within the next week.
- Ground Testing
 - CUBRC
 - Worked contracting/funding issues. A subcontract process in underway to get CUBRC funded.
 - APL reviewed CUBRC thin film location layout and provided suggested revisions back to CUBRC
 - Candidate layout of PCB's on CUBRC model provided consisting of all 10 PCB's on the main surface. The layout was generated using NASA Langley ceramic model heating images and APL boundary-layer stability results to place PCB sensors within expected transitional regions on the model.

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- Discussion of CUBRC test plans to be held at bi-weekly telecon on 12/22 with government team.
 - Purdue
 - Moved test date for first entry from 2/5/18 to 2/12/18 due to a tight fabrication schedule and need to get the model to Purdue early for TSP application
 - Received preliminary gutter testing results from Greg McKiernan at Purdue. It appears that at locations measured, the gutter does not seem to transition earlier than the main surface. Gutter remained laminar at maximum quiet pressure.
 - Held another test planning telecon with Purdue (Berridge/Wheaton/Schneider/McKiernan/Chynoweth) on 12/20. Discussion of Entry #1 scheduling, angle of attack uncertainty (Purdue quotes ~0.1deg is typical)
 - CFD/Stability
 - Additional comparison of stationary crossflow N-factors made with Texas A&M EPIC solutions, including the effect of curvature terms on the resulting N-factor.
 - Texas A&M has identified some possible additional mechanisms that are not crossflow present upstream near the leading edge in their stability solutions and they are investigating
 - APL re-processed some CFD solutions to generate FieldView files for comparison to thermal modeling
 - APL is adding turbulent cases to the queue to compare against thermal modeling from heating correlations
 - Communications with NASA Langley (Chau-Lyan Chang) re: LASTRAC code results.

12/23/2017 through 1/5/2018

- Upcoming dates/milestones:
 - 1/10/18 - Transition Open Forum presentation by APL @ SciTech
 - 1/19/18 - Requirements Review during bi-weekly telecon
 - 2/2/18 - CoDR (8am-5pm, **CORRECT address is 900 Glebe Road, 2nd Floor, Arlington, VA 22203**). See <https://community.apan.org/wg/afosr/w/researchareas/21795/2018-review-of-bolt-grant/> for more information (incorrect date currently displayed in image header)
 - 2/5/18 - Delivery of model and sting hardware to Purdue
 - 2/12/18-2/18/18 - Purdue subscale entry #1 (postponed one week to add margin to manufacturing timeline)
 - 2/16/18 - CUBRC estimate for model fabrication completion
 - 3/12/18-3/18/18 - tentative Purdue subscale entry #2
 - early March 2018 - CUBRC entry (7 runs)

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- CoDR planning efforts
 - Agenda planning with Joe Norris/Ivett Leyva. Draft agenda distributed and is almost finalized.
 - A Mission Requirements and Objectives review will be held as part of the regular bi-weekly government telecon on Friday 1/19. The purpose will be to make sure the derived requirements from the flight scientific objectives are agreed upon by all moving forward.
 - Work is underway to build out a template and slide count for the CoDR
 - Flight Geometry Design
 - Thermal analyses
 - Goal of current thermal work is to assess material selection, location of breaks in different Flight Geometry components, and assess peak temperatures (not yet coupled to loads). These cases are being run with a fully turbulent heat flux for now to be conservative.
 - The thermal grid and 3D transient conduction tools are working, however comparisons of correlation-based heat fluxes against CFD showed poor agreement on the swept leading edges. The correlation based fluxes were under-predicting heat loads on the leading edge.
 - The thermal conduction code has since been modified to apply more conservative correlations on the leading edge region, and new cases are running now.
 - As a backup, fully turbulent and adiabatic CFD runs were completed across both ascent and descent phase to generate heat transfer coefficients that can be used as a direct input into the thermal tool in case the new correlations are still in poor agreement with CFD.
 - Model being run with aluminum and titanium @ 3/4" thickness
 - Will desire independent comparisons of heat flux loads sometime after CoDR from UMN and/or TAMU, to verify that the grid created by APL is producing reasonably accurate fluxes
 - Inquired with AFRL/RQ why both steel isolator and stainless steel joiner components were used on HIFiRE-5, between the TZM tip and aft aluminum section. Roger Kimmel's notes indicated there was concern that stainless was a poor conductor and would keep the TZM too hot. Dave Adamczak ran cases with carbon and stainless isolators and saw little difference in the TZM nose temps. APL is looking at options with only one steel isolator component at this time.
 - Inquired with AFRL/RQ about any previous considerations of using titanium in past HIFiRE flights. It has not been used previously, but could be an option on BOLT if necessary.
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- Vatel heat flux gauges (6) have been re-included in the master instrumentation list. Initially they were removed based on high success of Medtherms reproducing heat fluxes on previous HIFiRE flights. However, BOLT data analysis will be challenged by higher 3D thermal gradients than the simple conical geometries and APL felt that selected Vatellets may be needed in challenging areas.
 - Ground Testing
 - Purdue
 - Model fabrication is underway
 - Working on details of a recessed Kulite design on the attachment line, which will be tested in Entry #1 for feasibility. The recessed design minimizes roughness on the leading edge and is based on previous design provided by Purdue. The downside to this method could be signal attenuation or resonance in the cavity.
 - Finalized locations for limited Kulite, PCB, and Schmidt Boelter instrumentation on the model for Entry #1.
 - Detailed design of sting interface is underway for Purdue tunnel.
 - CUBRC
 - Reviewed draft instrumentation at bi-weekly telecon with government team on Friday 12/22/17. A deadline was set at Friday 12/29/17 for obtaining feedback prior to finalizing instrumentation.
 - The instrumentation layout is now finalized so that CUBRC can proceed with detailed mechanical design.
 - The only changes from the 12/22/17 telecon are that instrumentation was moved to another quadrant such that the main instrumented surfaces are behind the smooth leading edge and away from the painted surfaces.
 - Also, two of the PCB's were moved slightly .125" farther from the model centerline (from 1" to 1.125" away from centerline). This move was required due to proximity to the model split and was approved by APL.
 - CUBRC subaward is very close to being finalized and APL subcontracts has created a start date of 1/1 allowing CUBRC to begin detail work and fabrication
 - Detailed CUBRC matrix planning and roughness trip sizing still needs to be completed while the model is being fabricated.
 - CFD/Stability
 - Ran new adiabatic and turbulent cases for support of thermal analyses.

1/6/2018 through 1/31/2018

- Upcoming dates/milestones:
 - 2/2/18 - CoDR (8am-5pm, **CORRECT address is 900 Glebe Road, 2nd Floor, Arlington, VA 22203**). See <https://community.apan.org/wg/afosr/w/researchareas/21795/2018->

[review-of-bolt-grant/](#) for more information (incorrect date currently displayed in image header)

- 2/1/18 - Delivery of subscale model to Purdue
 - 2/5/18 - Delivery of sting hardware to Purdue
 - 2/12/18-2/18/18 - Purdue subscale entry #1
 - mid- to late-February: CUBRC entry (7 runs)
 - 3/12/18-3/18/18 - tentative Purdue subscale entry #2
 - Spring 2018 TBD - subscale model to Texas A&M
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
- Flight Experiment Requirements Review (FERR) held on 1/26/2018
 - Worked with government team to develop and finalize flight experiments (primary/secondary/tertiary), objectives, primary/secondary requirements, milestones, CoDR entrance/exit criteria, and evaluation criteria
 - FERR conducted 1/26/2018 via telecon to present and finalize the documents outlining the above
 - Documents have been sent out for approval (1/30/2018) to be provided via e-mail from principals at each organization
- CoDR
 - Major activities over this timeframe have been to finalize materials for review at CoDR on 2/2/18 in Arlington VA
 - Slide presentation created to outline all major activities to date
 - CoDR internal dry run conducted for APL Steering Committee on 1/29/18
 - CoDR slides are now in the final review process for release ahead of this Friday
- AIAA SciTech 2018 Conference - open forum presentation and coordination meetings
 - Presented update on BOLT at the Transition Open Forum on 1/10/18
 - Held meeting with Texas A&M team to share and discuss recent computational and experimental results
 - Met with NASA Langley (Berry, Chang, Choudhari, Berger) to discuss NASA testing plans and LASTRAC results
 - Met with Graham Candler and Heath Johnson to discuss potential CFD and thermal analyses needed by PDR.
- Re-baselined overall fabrication and integration schedule ahead of nominal December 2019 flight test date
- Flight Geometry Design
 - Thermal analyses
 - Ran additional CFD points during ascent to add to the thermal model.

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- Re-ran thermal analyses with scaling factors applied to swept leading edge heating, to raise heating levels above turbulent CFD values. The model now includes margin in this critical area, both from the scaling factors and from the fully turbulent assumption. The amount of margin, however, needs to be assessed to ensure a proper amount of conservatism is being used.
 - The predicted temperatures are now being assessed relative to expected strength of materials at those temperatures. Some high temperatures are predicted in the swept leading edge area for both aluminum and titanium options. Results will be shown at CoDR
 - Generated thermal plots and data for CoDR presentation
 - Requested an independent transient thermal analysis from Minnesota to compare against the APL thermal model. This analysis is in progress and a status will be presented at CoDR.
 - Froze current design concept for presentation at CoDR. Baseline is TZM/Stainless/7075-T6 with an alternate of TZM/Stainless/Titanium
 - Completed initial interface concept for Payload System TSM RADAX plate
 - An overview of current mechanical design issues related to thermal modeling uncertainties will be presented at CoDR along with the current concept.
 - Ground Testing
 - Purdue
 - Model fabrication of the Purdue subscale model is now complete ([link to pictures and videos](#))
 - The subscale model includes a few more components than originally planned: a total of 3 aluminum primary surfaces were made, along with 1 PEEK primary surface. The extra aluminum surface will be useful for future tests if vastly different instrumentation layouts are desired.
 - The model was shipped to Purdue on Wednesday 1/31 to allow time for Purdue to paint the model with TSP the following week.
 - Some sting hardware components will be shipped to Purdue next week as they are still being finished.
 - CUBRC
 - Finalized subaward with CUBRC
 - CUBRC has finished fabrication of the full scale model and is beginning instrumentation work
 - CUBRC anticipates installing the model into LENS II by the middle of February
 - APL and CUBRC have been working to plan the baseline test plan for the 7 runs in LENS II, including swept leading edge roughness height locations and heights
 - CFD/Stability
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- APL has been analyzing existing CFD mean flows in order to calculate roughness correlations from the boundary-layer properties. These correlations are being used to define roughness tolerances for the flight experiment and to select candidate roughness heights for upcoming wind tunnel testing.
 - Candidate swept leading edge step heights have been compared to empirical numbers calculated by Roger Kimmel and also Mike Holden. The various correlations have been used to identify a range of step heights of potential interest for the flight experiment (0.005" to 0.040"). Two heights within this range will be selected for testing on the full scale CUBRC model.

2/1/18 through 2/9/18

- Upcoming dates/milestones:
 - 2/9/2018 - CUBRC test plan review telecon @ 3pm ET
 - 2/12/18-2/18/18 - Purdue subscale entry #1
 - mid- to late-February: CUBRC entry (7 runs)
 - 3/12/18-3/18/18 - tentative Purdue subscale entry #2
 - Spring 2018 TBD - subscale model to Texas A&M
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
- Flight Geometry Design
 - Thermal Analyses
 - Work continues to improve the thermal inputs into the APL model and to understand the margins gained from conservative assumptions.
 - The thermal heat fluxes have now been switch entirely from correlations to CFD-based values for ~90% of the trajectory due to the addition of several more CFD simulations. The model will be run with the new CFD-based inputs, in lieu of scaled correlations, to assess the effect on peak temperatures.
 - A second case will be run to switch between laminar and turbulent fluxes for the entire body at a chosen value of ReL, to assess effect on peak temperatures.
 - Minnesota has completed a transient coupled CFD/thermal analysis of the ascent phase and is currently post-processing the data.
 - Instrumentation
 - To support upcoming material choice decisions, APL built a 2D thermal model of a Medtherm thermocouple within a constant-thickness wall. The model is implemented in CFD++ in "solids only mode" to be used as a thermal solver. The thermal model was subjected to a variety of steady-state and transient heat flux loads to evaluate the thermocouple type and response rate within titanium, compared to aluminum. The analyses are ongoing.

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- Transcribed QCALC code into MATLAB to estimate 1D heat flux from temperature histories of front/back face thermocouples. Simulated front/back face temperatures from the above 2D thermal model will be used in QCALC to calculate heat flux, and compared to the input heat flux.
 - AFRL has asked GoHypersonic to run their thermal model of the PCB sensors with a titanium wall instead of aluminum. This would be for a different geometry with slightly different trajectory, but might help to show whether the PCB sensors are adversely affected by the higher surface temperatures in titanium.
 - Ground Testing
 - Purdue
 - Subscale model and supplies arrived at Purdue last week
 - Model is still being prepared - some problems getting the paint to adhere so it had to be done twice. Sensors are installed.
 - Dennis Berridge travels to Purdue Tuesday-Friday next week.
 - Sent run matrix to Greg McKiernan for the first three days of the entry.
 - Ran roughness correlation for Purdue conditions - data indicates needing at least 0.050" strip to trip flow.
 - CUBRC
 - Completed plots justifying selection of 0.010" and 0.030" candidate trip heights for CUBRC testing.
 - CUBRC test plan review telecon Friday 2/9 at 3pm ET.
 - CFD/Stability
 - Established a standing biweekly telecon for CFD/stability analyses on Fridays at 2-3pm ET (occurring on off Fridays from the government team biweekly). The telecon will be used to have discussions related to ongoing analyses, share results, and improve coordination of analyses.
 - UMN/VirtusAero provided wall variables from independent grid for comparison to APL grid results. A spot check of laminar heating rates and BL edge conditions along the highly swept leading edge showed very good agreement. The edge conditions are used to calculate roughness height correlations. The independent comparison gave additional confidence to the roughness trip height sizing analyses for the CUBRC test, and to heating rates being passed from CFD to APL thermal analyses.
 - Ran additional laminar and adiabatic cases to support additional points on the trajectory currently being used for thermal analyses.

2/10/18 through 2/16/18

- Upcoming dates/milestones:
 - 2/12/18-2/18/18 - Purdue subscale entry #1

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- ~2/21/18 - CUBRC entry first run
 - mid to late April (delayed from mid March) - tentative Purdue subscale entry #2
 - Spring 2018 TBD - subscale model to Texas A&M
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
 - Flight Geometry Design
 - Thermal Analyses
 - New (mostly) CFD-driven thermal model is being implemented but no results are available yet
 - Downloaded and inspected new converged CFD cases to be used for heat flux input
 - Started to implement discrete time transition on new CFD-driven model
 - Minnesota is working to fix a bug in their coupled CFD/thermal code
 - Instrumentation
 - Documented initial thermal analyses of Medtherm thermocouples ([link to slides](#)), intended to explore impact of wall material choice on reconstruction of heat flux from front/back face thermocouples.
 - Type E seems most appropriate match for Titanium wall
 - Both Aluminum/Type-T and Titanium/Type-E seem capable of indicating transition with rapid response times, however the thermal lag in Titanium could result in more difficulty achieving accurate heat flux amplitudes
 - The larger temperature gradient in Titanium will likely require using temperature-dependent material thermal properties when reconstructing the heat flux with an inverse solver
 - Received input from AFRL/RQ (Kimmel and Adamczak) based on their experiences with the Medtherms
 - Potential concern of Loctite bonding strength at higher temperatures that would be seen in Titanium
 - Differential thermal expansion of Type E in Titanium would need to be checked. CTE of Chromel (Type E) is actually larger than Titanium, so the Type E would expand more (outwards/protruding).
 - Thinner wall for Titanium may aggravate lateral conduction
 - Larger sensitivity and higher temperatures in Titanium may require some minor amplifier/conditioning board changes by AFRL/RQ
 - Ground Testing
 - Purdue
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- Entry #1 with the subscale model is ongoing this week. Greg McKiernan has been running the tunnel for us, and Dennis Berridge supported from APL.
 - After some initial problems with the TSP, the test is going well.
 - Simultaneous TSP and IR images are being obtained. The TSP is giving a much better view of the transition front, while the IR better shows the flow features (streaks, etc.).
 - Measurements on the swept leading edge are challenging, and it is unclear if either of the instrumentation methods tested in this entry will work. The paste-on hot film did not adhere due to the high curvature of the swept leading edge. It is unclear right now if the recessed Kulite (within a cavity) is able to measure transition until the data can be further analyzed.
 - Measurements are being taken at 0, 2, and 4 degrees angle of attack with various roll angles. At 4 degrees AoA, roll angle of 0, 30, 60, and 90 were tested and are yielding some interesting images.
 - Due to a delay in the installation of the new Purdue throat, Entry #2 has been pushed back from mid-March to mid/late April.
 - Arrival of APL Kulites now expected sometime after 2/28/18 ship date.
 - CUBRC
 - After further analyses and discussions with CUBRC, it was decided to leave the 0.010" and 0.030" trips for the first test point.
 - CUBRC has completed instrumentation and installation of the trips. Epoxy has been added to fair the trips on the sides and downstream ends to approximate a true "2D" step. The epoxy is curing and will be sanded.
 - CUBRC finished applying the TSP binder and TSP outer layer, along with sanding. Photos have been added from 2/16 showing the TSP ([link to photos](#))
 - The model is being installed in the tunnel either Friday 2/16 or Monday 2/19. First run would be expected within a few days after that.
 - Texas A&M
 - APL is working with TAMU to coordinate lending components of the subscale model in the hopes of enabling testing at TAMU sooner, without needing to coordinate with all the other facility schedules.
 - CFD/Stability
 - APL documented comparison of CFD wall variables ([link to slides](#)) such as edge conditions, Re_{θ}/M_e , etc. APL's calculated wall variables from CFD++ were compared against US3D wall variables on the same grid. The comparisons were done to verify that the wall variables calculated by APL are accurate.
 - APL is running a variety of potential CUBRC test points ahead of the wind tunnel entry so that laminar and turbulent heat flux data will be available to rapidly assess transition in

order to make decisions on future test points. The Mach 5.25 cases are expected to be completed before the first run at CUBRC.

2/17/18 through 2/23/18

- Upcoming dates/milestones:
 - 2/12/18 to 2/18/18 - Purdue subscale entry #1
 - 2/22/18 to early March - CUBRC entry
 - 4/23/18 to 5/4/18 - tentative Purdue subscale entry #2
 - mid-May OR mid-to-late June - NASA Langley 20-Inch M6 entry windows
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
- Flight Aerodynamics
 - Held more discussions with AFRL/RQ regarding status of aerodynamic stability CART3D analyses and potential fairing design decision points. AFRL/RQ is planning additional analyses of the full stack and has looked parametrically at how the fairing length might affect stability.
 - Ryan Gosse of AFRL/RQHF is planning to run CFD analyses of separated flow effects from the overhanging BOLT geometry on the booster fins. These analyses will help answer if a fairing might be needed to mitigate any potential separated flow concerns. APL provided Ryan with CAD files and existing grids of the Flight Geometry if needed to assist his analyses.
 - It seems that decision on existence and/or shape of a fairing could happen after freezing the interface design between the Flight Geometry and the Payload System. Both Tom Wolf and Dave Adamczak agreed there would be ways to easily mount a fairing to both components later in the design process (or perhaps even after fabrication has started). This would reduce risk of the fairing/no-fairing decision point to impact schedule, and allow DLR to be on contract to help make the determination.
- Flight Geometry Instrumentation
 - Phone calls with Medtherm regarding lead time for large order of coaxial thermocouples. Medtherm indicates a lead time of 4-6 months. APL is targeting mid-May to finalize an order.
- Ground Testing
 - Purdue
 - Purdue subscale model entry #1 was completed and the model and data were returned to APL.
 - Greg McKiernan processed the TSP data to heat transfer and included that on the hard drive that was sent with the model
 - Currently processing the data to aid in decision making for instrumentation placement for second entry

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- The attachment line recessed Kulite appears to give questionable data to indicate transition on the swept leading edge. The recessed method may not have worked.
 - One Kulite on the centerline to track the state of the boundary layer in the central vortex dominated flow region. Transition was measured in that region but it did not appear to happen before the outboard region. Need to determine if turbulent flow measured in the central region is spreading to there from the outboard region.
 - CUBRC
 - Model was installed in LENS II
 - Dennis Berridge is supporting the test on site at CUBRC for APL
 - CUBRC desired to perform a checkout run of some new tunnel upgrades at lower pressure than the initially desired first test condition.
 - A run was performed at Mach 5.25/ReL=5e6 on Thursday 2/22
 - The second run will also be at Mach 5.25 at a different Reynolds number to be determined
 - NASA Langley
 - Held planning telecon with Scott Berry and Rudy King regarding upcoming testing plans for the APL subscale model, the NASA PEEK roughness model, and potential options for ceramic model testing.
 - NASA currently is holding a test slot for BOLT subscale model testing in mid-May.
 - It is likely that APL will switch entry slots and let NASA's BOLT PEEK model be tested in mid-May, with a mid-June slot for the APL model. The advantages to this swap would be that NASA'S PEEK model could be evaluated for high heating loads on the swept leading edges to reduce risk of damage to the APL model PEEK component. The swap also allows more buffer between the planned Purdue and Langley entries. A June test would permit significantly more student interns (at APL and also NASA) to be involved in the testing of this model.
 - Texas A&M
 - Purdue shipped spare APL subscale model parts to Texas A&M (due to arrive 2/23)
 - Texas A&M is planning to build and instrument remaining model components for a second subscale model
 - CFD/Stability
 - APL processed 20 mean flows for potential CUBRC test conditions for both laminar and fully turbulent assumptions. Extracted heat transfer from leading edge to help diagnose transition from the trips.
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- Ran LASTRAC to compute 2nd mode and stationary crossflow N-factors for 10 potential CUBRC test conditions and extracted data for comparison against test results

2/24/18 through 3/2/18

- Upcoming dates/milestones:
 - 2/22/18 to mid March (?) - CUBRC entry
 - 2/22: tunnel checkout run M5.25/5e6 completed
 - 2/26: Run 2 completed (M5.25/10e6)
 - 2/28: Run 3 completed (M5.25/3e6)
 - 3/1-3/2: CUBRC internal use noise effects runs (2)
 - 3/6: Scheduled throat insert change to permit Mach 7 runs
 - 3/7: Anticipated date for Run 4 at Mach 7
 - 3/8-3/13??: Runs 5-8 at Mach 7
 - 4/23/18 to 5/4/18 - tentative Purdue subscale entry #2
 - mid-May OR mid-to-late June - NASA Langley 20-Inch M6 entry windows
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
- Thermal Analysis
 - The newest round of thermal analysis has been completed with most of the trajectory using viscous CFD-based heating.
 - Fully laminar or fully turbulent viscous CFD heat fluxes have been mapped to the thermal grid for the most important (high dynamic pressure) portions of the trajectory on ascent and descent.
 - For the remainder of the trajectory, the correlations are still being used. As presented at CoDR the correlations agree well with CFD for the nosetip and flat portions of the geometry but are still overpredicting heat flux on the swept leading edge. However, now the swept leading edge correlations are mainly being used only for lower heating portions of the trajectory as opposed to at CoDR where they were being used for more relevant parts of the trajectory.
 - Comparison of 1020 Steel vs. Stainless Steel mid component showed minimal effect on aluminum peak temperatures.
 - The new CFD-based thermal model was compared against purely correlation-based models for both fully laminar, fully turbulent, and with crude transition models.
 - In general the fully turbulent CFD-based/correlation-based temperatures are reasonably similar in terms of peak temperatures.
 - Switching entirely to/from laminar/turbulent fluxes at $Re_L=3e6$ had minimal effect on the peak temperatures (swept leading edge heating was still higher than desired). However this is also an over-conservative estimate.

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- A fully laminar assumption (unrealistic) showed that peak temperatures on the swept leading edge decrease from ~625K to ~450K. The real answer is somewhere between...
 - Thermal path forward identified
 - We now have test data from CUBRC showing that the swept leading edge is quite laminar and is resistant to being tripped to turbulent.
 - The thermal model is already set up to map CFD-based heating from viscous CFD, but we have previously only run fully laminar and fully turbulent CFD for the thermal inputs.
 - APL is now planning to run new CFD cases with transition modeled within the viscous CFD. The flow will be tripped from laminar to turbulent at $Re_{\theta}/M_e=150$ contour lines, obtained from the laminar CFD at those same time conditions. This will keep the leading edge mainly laminar through the experiment windows, except for conditions where turbulence spreads from the main surface. Thus, a new set of CFD inputs will be obtained with modeled transitional heating will be used for the "final high fidelity" thermal model.
 - Correlation-based models will still be needed for new trajectories that include modeling of off-nominal AoA/beta, or when CFD cases are not available, so efforts are still underway to improved the correlation-based fluxes as well.
 - APL is currently testing tripping methods and plans to launch the transitional CFD cases with new thermal analysis to be completed within the next week or two.
 - Ground Testing
 - Purdue
 - Currently analyzing TSP and IR image data to propose an instrumentation layout for the second entry (12 PCB's, 12 Kulites)
 - The second entry at Purdue has been pushed back to start on 4/23/18
 - CUBRC
 - 3 runs have been performed at Mach 5.25 with duplicated freestream velocities ($Re_L = 3e6, 5e6, \text{ and } 10e6$)
 - APL decided the remaining runs will all be at Mach 7, which requires CUBRC to move to change out the throat insert to allow higher Mach numbers as planned. The throat insert change is currently scheduled for Tuesday 3/6, with the first Mach 7 run anticipated on Wednesday 3/7.
 - At the Mach 5.25 conditions, all attempted trips have been ineffective at promoting turbulent flow on the swept leading edge attachment lines. This includes the 0.010" and 0.030" forward-facing steps. The swept leading edge remained laminar even at $Re_L=10e6$ where transition was expected at least for the 0.030" step.

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- CUBRC has removed the 0.010" forward-facing step and replaced it with a 0.030" sand-grain distributed roughness patch for upcoming runs. It is unknown if either the 0.030" 2D step or sand-grain roughness will cause transition at Mach 7.
 - Because of the down time while waiting to change the throat insert, CUBRC asked permission to use our model to obtain data under internal funding to add to their tunnel noise effects database. CUBRC plans two of their own runs matching Purdue Quiet Tunnel Reynolds numbers at Mach 6, one at matched Purdue conditions and one at higher total enthalpy.
 - NASA Langley
 - Worked with Langley to modify some of the partnership milestone dates on the Space Act Agreement draft to correspond to new estimates of tunnel entries.
 - Space Act Agreement is nearing finalization.
 - CFD/Stability
 - Held another bi-weekly CFD/stability telecon where Alex Moyes from TAMU shared some of his recent preliminary analyses with the team.
 - APL is beginning to run CFD mean flow solutions at as-run CUBRC test conditions. When the test conditions have been received from CUBRC they will be posted on SharePoint so that others can compare to the CUBRC data.
 - APL is running new flight cases with transitional heating modeled, with tripping at constant Re_{θ}/M_e , to support thermal analyses.
 - Re_{θ}/M_e contour lines were extracted from all existing laminar mean flows at flight conditions and converted into CFD++ format for tripped flow inputs.
 - Tripping is being modeled with the 1-eq. SA turbulence model in CFD++.
 - Freestream turbulence parameters were adjusted to obtain laminar flow upstream of the trips.
 - A variety of tripping radii and turbulence source term parameters were studied by APL at one condition to attempt to ensure tripped flow without excessive localized heating at the trips.
 - An ideal set of tripping parameters was identified and used to launch cases at all flight time steps. The cases are now running and should be finished by Monday, at which point they will be examined individually to ensure ideal tripping behavior.
 - When all tripped cases are finalized and converged, the heating data will be passed back to the thermal analysis code for updated temperature predictions.

3/3/18 through 3/9/18

- Upcoming dates/milestones:

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- 2/22/18 to mid March (?) - CUBRC entry
 - 2/22: tunnel checkout run M5.25/5e6 completed
 - 2/26: Run 2 completed (M5.25/10e6)
 - 2/28: Run 3 completed (M5.25/3e6)
 - 3/1-3/2: CUBRC internal noise effects runs (M6/3e6 - Purdue and Flight)
 - 3/6: Scheduled throat insert change to permit Mach 7 runs
 - 3/8: Run 4 completed (M7/5e6/2500R)
 - 3/9: tentative date for Run 5 (M7/3e6/3500R)
 - 3/12-3/14?: Runs 6-8
 - 4/23/18 to 5/4/18 - tentative Purdue subscale entry #2
 - mid-May OR mid-to-late June - NASA Langley 20-Inch M6 entry windows
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
 - Thermal Analysis
 - CFD-based "tripped flow" heating cases were completed and fully implemented into the transient thermal solver. Slides created to show the heating comparison between the laminar, tripped, and fully turbulent heating ([link to slides](#))
 - The model was run with several different laminar/turbulent flow assumptions and the MAX temperature at t=488s was compared only for the aft (aluminum 2024) section:
 - Fully turbulent: 639K
 - Fully laminar (not realistic): 458K
 - Tripped at $Re_{\theta}/Me=150$: 573K (including model of transition reduced maximum temperature by nearly 70K. Bulk temperature was also reduced slightly)
 - Effect of aft material choice on max temperature at 488s (assuming TZM nosetip and 1020 steel mid section):
 - Titanium 6A1-4V: 835K
 - Aluminum 2024: 573K
 - Aluminum 6061: 557K (6061 aluminum has slightly higher conductivity than 2024 or 7075, and also has better strength at higher temperature as noted by Dave Adamczak at CoDR)
 - We now have a much better handle on our temperature margins and conservatism. It seems that with better modeling of transitional flow heating our maximum temperatures at 488s are much better, closer to 560K.
 - Ongoing/future work:
 - Run model with Aluminum 6061 and Stainless Steel mid section to see if lower conductivity of stainless will reduce temperatures even more
 - Evaluate locations of material break points

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- Consider adding more thermal mass near leading edge to reduce temperatures even further
 - Examine virtual thermocouple data to assess 3D conduction effects on heat transfer estimation
 - Flight Geometry Instrumentation
 - Ran simple thermal analysis of 2D "slice" of aft section to examine 3D conduction effects.
 - Conduction from the higher heating at the swept leading edge causes higher temperatures that appear to eliminate the applicability of the 1D assumption on reducing thermocouple data to heat flux (at least for >50% of the span on the main/upper surface)
 - Working to identify a plan to compensate for 3D conduction to estimate heat flux from the Medtherms in flight. A 2D inverse heat transfer solver is being considered for various streamwise planes of the geometry.
 - Ground Testing
 - Purdue
 - Working on instrumentation layout for follow-on Purdue entry
 - On standby pending improvement of quiet pressure via cleaning or new throat
 - Analyzing data. [TSP images](#) have been posted onto SharePoint.
 - Kulite sensors arrived at APL for subscale model this week (ordered in September!)
 - CUBRC
 - CUBRC completed two runs at Mach 6 matching Purdue Reynolds number $\sim 3e6$
 - First run at Mach 7 was completed on Thursday 3/8 following change of the throat insert
 - NASA Langley
 - Final Space Act Agreement draft is ready for signature by APL and NASA
 - CFD and Stability
 - Tripped CFD cases at flight conditions have been completed and used for thermal analysis
 - Minnesota provided US3D turbulent heating data to compare against APL CFD++ turbulent heating. A comparison was made for one case and is posted on SharePoint ([link to slides](#)).
 - Laminar, transitional, and turbulent drag comparison was made from CFD for the BOLT configuration per Ivett's request.
 - VirtusAero is completing some STABL-3D analyses at flight conditions.

3/10/18 through 3/16/18

- Upcoming dates/milestones:

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- 2/22/18 to mid March (?) - CUBRC entry
 - 2/22: tunnel checkout run M5.25/5e6 completed
 - 2/26: Run 2 completed (M5.25/10e6)
 - 2/28: Run 3 completed (M5.25/3e6)
 - 3/1-3/2: CUBRC internal noise effects runs (M6/3e6 - Purdue and Flight)
 - 3/6: Scheduled throat insert change to permit Mach 7 runs
 - 3/8: Run 4 completed (M7/5e6/2500R)
 - 3/14: Run 5 completed (M7/3e6/3500R)
 - 3/16?: Run 6 tentative planned (M7/5e6/2500R/BETA=2)
 - 3/18-3/19?: Runs 7 and 8?
 - 4/23/18 to 5/4/18 - tentative Purdue subscale entry #2
 - mid-May OR mid-to-late June - NASA Langley 20-Inch M6 entry windows
 - July 2018 - Preliminary Design Review (PDR)
 - September 2018 - Critical Design Review (CDR)
 - Thermal Analysis
 - Additional thermal analysis runs have been completed to look at parametric design effects on maximum temperatures
 - We are now working with a TZM nosetip, followed by 304 Stainless mid section, and Aluminum 6061 aft section as our baseline design
 - A 2D/centerline model was run to evaluate parametric effects from different nosetip and mid-section lengths on maximum temperatures
 - The length of both the TZM nosetip and the steel mid-section were varied each by +/-1.5"
 - The reduction in maximum aluminum temperature was almost negligible with lengthening of the steel section, at least in the 2D model.
 - The full 3D model was run with axial conduction between the materials disabled. The purpose was to evaluate how much of the temperature rise in aluminum is due to heat conduction from the upstream steel mid-section. The maximum temperature in Aluminum just prior to descent decreased by only about 7-8K, suggesting that most of the heat added to that component is from convective heating and not conduction from upstream.
 - The full 3D model was also run with a "solid" or "filled" steel mid-section to add material with the highest specific heat capacity per unit weight. Filling the steel reduced the maximum Aluminum temperature by about 10K during the descent phase.
 - Flight Geometry Instrumentation
 - Virtual front and back face thermocouples were provided from the APL thermal model using the CFD-based "tripped" trajectory model.
 - Thermocouples were provided on the Flight Geometry centerline and on the highly swept leading edge, for the aluminum aft component.
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- The descent data only are currently being analyzed, as the ascent data were not provided starting at $t=0s$ (an initial steady state is needed for QCALC)
 - On centerline where the flow is mainly 1D, the QCALC inverse solver has no problem identifying transition from change in heat transfer. Transition can be seen in each of the thermocouples progressing upstream
 - On the swept leading edge, turbulence from the main surface that contaminates the leading edge can be seen in the 1D heat flux.
 - However, a problem was identified from the upstream swept leading edge thermocouples. The problem occurs when the attachment line remains laminar, but the flow just past the attachment line is turbulent. Heating conducts through the leading edge and causes a rise in the front-face thermocouple temperature that could lead to false indicated attachment line heating in flight. This finding highlights the importance of including transient conduction effects in reduction of the flight data.
 - Medtherm confirmed that the coaxial thermocouples CAN be installed at an angle relative to the surface. This may help us add more thermocouples closer to the swept leading edge.
 - It is becoming likely that a 2D inverse solver will need to be developed in order to fully understand heating near the swept leading edge. This capability is available in CFD++.
 - Ground Testing
 - Purdue
 - Working on instrumentation layout for follow-on Purdue entry
 - On standby pending improvement of quiet pressure via cleaning or new throat
 - CUBRC
 - Status of runs and testing posted above in dates/milestones.
 - Data have been received for Runs 1-5 and preliminary results have been posted on SharePoint
 - CSV files include mean thin film heat flux and run freestream conditions
 - TSP images are also posted
 - APL is working to collect data into a set of slides
 - Two Reynolds numbers have been completed at Mach 7.
 - The next case is a 2-deg sideslip case at $Re_L=5e6$. It is likely that the angle of attack case at 2 degrees will also be performed.
 - NASA Langley
 - Final Space Act Agreement for NASA/APL collaborations has been fully executed
 - Texas A&M
 - Texas A&M is currently building the missing subscale model components using the spare APL parts and expects to be testing by April
 - CFD/Stability
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- New CUBRC mean flows completed
 - Developed scripts to interpolate and plot thin film heat flux data vs. laminar and turbulent heating
 - VirtusAero has completed initial STABL-3D results for the 2nd mode instability

3/17/18 through 3/23/18

- Ground Testing
 - Purdue
 - Initial instrumentation layout was evaluated and decided that large changes needed. Purdue offered to lend 4 or more PCB-132 sensors for the model.
 - Schedule for test will be delayed pending the re-installation of the nickel throat and increased performance.
 - CUBRC
 - Final runs completed, including a 2-degree angle-of-attack run and a zero-degree angle-of-attack run at $Re_L=12e6$.
 - Data from the runs was received by APL.
- Thermal Analysis
 - Work is continuing to create converters between software tools to allow the calculation of thermal stresses in the model.

3/24/18 through 4/27/18

- Upcoming dates/milestones:
 - early May - Texas A&M testing with APL subscale model in ACE and M6QT
 - 5/19/18 - BOLT exhibit at Military Invention Day
 - 6/20/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 6/25/18 - BOLT/HIFIRE session at AIAA Aviation 2018, Atlanta GA (papers from APL, Minnesota, and TAMU)
 - 7/16/18 to 7/27/18 - current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Program Schedule
 - Due to DLR not yet being under contract, and the estimated date of contract not occurring until at least summer, the team discussed at the BOLT program telecon delaying PDR from July 2018 until sometime after DLR has been under contract.
 - The effects of delay if DLR contract on cost and schedule are being analyzed.
 - Produced new financial information numbers showing current expenditures and revised projected expenditures against proposed spending rates.
- Thermal Analysis

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- Work is continuing to create converters between software tools to allow the calculation of thermal stresses in the model. This work is being supported by other projects.
 - Extracted simulated thermocouple data from the APL thermal analysis and working to plot the heating rates against axial distance.
 - Metacomp (CFD++) is working to implement new thermal boundary conditions (time- and spatially-dependent heat flux and temperature) that will allow some feasibility studies of 2D inverse heating solutions to be used for estimating flight heat transfer rates.
 - Once the boundary conditions are implemented, a demonstration simulation will be performed to test potential flight data reduction methods.
 - The development version of CFD++ with these features has been delivered to APL and will be compiled on our cluster soon
 - Ground Testing
 - Purdue
 - Delivery of the polished nickel throat has now been delayed to 4/30, which has made our mid-May test window unfeasible.
 - Held telecon with Purdue to discuss new tunnel availability. The test window was moved to July 16-27, after the
 - Instrumentation holes have been added to the subscale model. Machining was completed on Monday 4/23.
 - Design of new roughness inserts for the Purdue experiments are underway. It was decided to attempt to excited the stationary crossflow mode for some of the roughness experiments, using either distributed or spanwise arrays of trips.
 - Obtained Minnesota DNS heating results at Purdue conditions to help identify the spanwise wavelength of the stationary crossflow streaks.
 - LSTRAC results are also being used to estimate the stationary crossflow wavelengths.
 - CUBRC
 - All CUBRC runs have been completed.
 - CUBRC is working on delivery of the final data package and updated freestream conditions by the subcontract end date of 4/30.
 - APL performed CFD at the initial CUBRC conditions and provided some potential differences in heating rates for CUBRC to examine.
 - CUBRC corrected some calibrations and errors in the preliminary thin-film data files
 - Once all data have been received, the final data package will be posted to SharePoint for the team to analyze, to replace the preliminary data that is currently on SharePoint

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- NASA Langley
 - NASA had been re-shuffling the 20-Inch Mach-6 Tunnel schedule following a longer than expected return to service after repairs. We were working with NASA Langley to determine if our original expected test window of mid-June can still hold. If not, the test will need to be rescheduled.
 - Currently the 20-Inch Mach-6 Tunnel is back on line and we are penciled for an entry window of 6/20 through 7/10/18.
 - Scott Berry's PEEK model experiments on BOLT are scheduled for an earlier window of 5/30 to 6/19. However, if he experiences issues with delivery of his model then APL will attempt to be ready to swap entries with Scott and take the earlier window.
 - Texas A&M
 - Following telecons and e-mails to work out a new tunnel schedule for Purdue and Langley, we shipped the APL subscale model to Texas A&M to undergo testing in the ACE and M6QT tunnels.
 - TAMU has agreed to return the model to APL by 5/11 for preparation for the Langley entry.
 - CFD/BL Stability
 - Alex Moyes from Texas A&M presented analyses of the 2nd mode at flight conditions using Linear PSE rather than LST. He noted that using LPSE the 2nd mode N-factors are showing strong growth near the swept leading edges at higher Reynolds numbers, confirming the same phenomena observed in early LST analyses by APL. The same phenomena have been observed in STABL-3D results. It appears that at higher Reynolds numbers, the 2nd mode could be cause transition up near the highly swept leading edges.
 - Heath Johnson is completing stability results with STABL-3D at flight and CUBRC test conditions
 - John Thome from Minnesota presented new high-order CFD results at the same flight conditions, showing stationary crossflow modes being excited in extremely local regions of the primary experiment surface.

4/28/18 through 5/25/18

- Upcoming dates/milestones:
 - 6/20/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 6/25/18 - BOLT/HiFiRE session at AIAA Aviation 2018, Atlanta GA (papers from APL, Minnesota, and TAMU)
 - 7/16/18 to 7/27/18 - current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status

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- TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
 - APL summer interns
 - Heather Kostak, John Thome, and Greg McKiernan arrived at APL for summer internships on May 14th. Heather and John will be working BOLT this summer at APL.
 - AIAA Papers
 - The BOLT team completed four AIAA papers for AVIATION 2018 (APL overview, APL/Purdue/CUBRC ground testing, TAMU stability, and Minnesota high order CFD).
 - Military Invention Day 2018
 - BOLT was featured at a booth at Military Invention Day 2018, May 19th, at the Smithsonian Museum of American History.
 - Coordinated transportation and safe handling of the CUBRC model (300 lb crate) to the event.
 - Created video slideshow for the exhibit
 - Flight Geometry Instrumentation
 - Work is currently underway to assess the influence of significant 3D conduction effects expected on the BOLT geometry on the resulting thermocouple measurements.
 - John Thome is performing some transient conduction analyses this summer using CFD++. The purpose of these analyses are to assess the effect of 3D conduction on the data analysis plan, and to explore potential methods to use a 2D inverse solver to analyze the flight data.
 - Thermal Analysis
 - Documented current thermal analysis progress in AIAA paper.
 - Creating slides for AIAA talk that will double as a detailed status update on the thermal analysis for the BOLT team
 - The "tripped flow" thermal analysis simulates transition via an $Re_{\theta}/M_e=150$ definition, and uses heat transfer rates from viscous CFD. Viscous CFD is used during ascent and descent, with correlations used elsewhere.
 - Modeling tripped flow decreases the maximum aluminum temperature from 616K to 554K at the end of descent, using the Woomera trajectory
 - Details will be in the AIAA paper
 - Ground Testing
 - Texas A&M
 - Heather Kostak completed testing with the APL subscale model at Texas A&M ACE and Mach-6 Quiet Tunnels. She brought the data to APL where she is working to analyze it.
 - NASA Langley

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- The team is busy preparing for the NASA Langley testing with the APL subscale model, scheduled to occur in late June 2018.
 - Working with Langley to design a new sting interface with their facility and demonstrate a completed stress analysis
 - Planning details of instrumentation interfaces and data acquisition
 - A goal of this Langley entry is to obtain more ground test data on roughness-induced transition, specifically to assess tolerances of component interfaces. Heather is currently looking at scaling of potential flight roughness to NASA Langley conditions so that relevant roughness sizes can be selected.
 - There will be two roughness configurations planned for Langley. A 2D strip near the nosetip junction will test effects of step mismatches on transition. Also, an insert on the leading edge will be designed with parametrically varying steps as well.
 - CUBRC
 - Receive revised freestream conditions from CUBRC. Some runs changed significantly from the initial estimate. Run 2 was actually completed at $Re_L=17e6$ as opposed to the requested $Re_L=10e6$.
 - Ran new CFD at revised conditions and used comparisons of stagnation point heat transfer to assess the new conditions.
 - Still awaiting delivery of some data from CUBRC - final PCB data and gutter TSP files.
 - Purdue
 - Second Purdue entry with the subscale model is currently planned for late July.
 - Some of the roughness experiments at Langley will also be performed at Purdue under noisy and quiet flow, for comparison to the Langley data.
 - CFD/Stability
 - Alex Moyes submitted a paper with TAMU's stability results to AIAA Aviation.
 - John Thome submitted a paper with Minnesota's high-order CFD work to AIAA Aviation.

5/26/18 through 6/8/18

- Upcoming dates/milestones:
 - 6/18/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 6/25/18 - BOLT/HIFIRE session at AIAA Aviation 2018, Atlanta GA (papers from APL, Minnesota, and TAMU)
 - 8/27/18 to 9/7/18 - (pushed back from July 2018) current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status

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- AIAA Papers
 - Completed abstract for AIAA SciTech 2019 to focus on remaining ground testing at Purdue and Langley
 - Completed slides for Aviation 2018 Overview paper
 - Flight Geometry Instrumentation
 - John Thome is continuing to run temporal/spatial simulations of conduction using CFD-based heat fluxes to assess the effect of 2D conduction on the BOLT thermocouple measurements
 - John is working to optimize the placement of measurement locations on a particular axial station that would best capture the temperature history distribution
 - Working on comparisons of these 2D decoupled solutions at APL to 3D conjugate heat transfer solutions being performed at Minnesota
 - Requested HIFIRE-5B flight data which will be used to validate the APL 2D inverse solver, comparing against the predicted 1D heat flux loads
 - Scheduling visit to AEDC Tunnel 9 for education on the Medtherm Coaxial thermocouple instruments (nominally Tuesday 6/19)
 - Ground Testing
 - NASA Langley
 - Completed internal review of NASA Langley Test plan to APL Steering Committee (APLSC) on 4 June 2018.
 - NASA Langley Test Plan was presented to the government team during a telecon on 7 June 2018.
 - Heather completed installation of sensors and packed up the model, which was shipped to Langley on 6 June 2018
 - Selected roughness heights for testing during the NASA test, with the goal of gathering data on allowable 2D step roughness for the flight vehicle. Roughness heights were selected by examining potential flight roughness Reynolds numbers and scaling to the roughness Reynolds number and notional Langley test conditions, including wall temperature ratio effects.
 - Purdue
 - Purdue entry was delayed from the previous 7/16/18 start date to 8/27/18 start date, due to the July start date being too close to the end of the Langley test window.
 - CFD/Stability
 - Alex/John presented their papers to the CFD/stability working group at a telecon on Friday 1 June 2018.

6/9/2018 through 6/15/2018

- Upcoming dates/milestones:

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- 6/18/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 6/25/18 - BOLT/HIFiRE session at AIAA Aviation 2018, Atlanta GA (papers from APL, Minnesota, and TAMU)
 - 8/27/18 to 9/7/18 - (pushed back from July 2018) current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
 - Flight Geometry Instrumentation
 - Kulite pressure transducers for Flight Geometry
 - Obtained updated information from Kulite on specifications and availability of Kulite XCEL sensors for the flight geometry
 - The XCEL-100 sensors no longer come with an option for a 5psi range with the full 100mV output, this option has been ordered in the past by AFRL/RQ but is apparently discontinued. The lowest leadless diaphragm Kulite reports available is 15psi.
 - XCE sensors are available with standard bonded diaphragms in the 5psi range which is a less robust options, but may be worth considering if increased sensitivity is needed
 - Kulite delivery ranges are currently running 18 weeks, per Jim Vail
 - Medtherm Coaxial Thermocouples
 - Confirmed with Medtherm that the thermocouples can be ordered with extra length for a cost of \$125/inch. This is likely the route we will choose so that we can place an order this summer, before the Flight Geometry detailed design is completed.
 - Medtherm confirmed there are no problems cutting off excess length as long as it is done cleanly with a flat square surface
 - Asked Medtherm about including some gauges in the final milling pass. Dale said that he doesn't know if anyone has tried this, but he sees no reason it wouldn't work. He recommended the last few passes are removing 0.0001" increments and then you would still need to sliver the TCS with hand sanding. This is a riskier process but will be worth considering for regions where waviness created by hand sanding would potentially have effects on the experiment (highly swept leading edge). Testing would be needed before proceeding with this on the Flight Geometry.
 - APL will be visiting AEDC Tunnel 9 to meet with their test managers and technicians about the Medtherm gauges, which are used routinely at Tunnel 9.
 - Thermal Analyses

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- ABAQUS plugin is complete and undergoing testing (funded by other programs). BOLT is being used as the test geometry for the plugin. The thermal/structural analysis is being targeted for August or September completion. The analyses will be used for assessing thermal stresses in flight and for predicting thermal expansion of the complex leading edge shape.
 - John Thome is working on the 2D inverse heat transfer solver to be used for analyzing the flight data
 - The inverse solver workflow development is completed and is being tested
 - Working on building a database of BOLT descent solutions for laminar, turbulent, and tripped heat fluxes and temperature distributions from the inverse solver.
 - Initial testing of the inverse solver on BOLT looks promising. Progress was presented at an APL Steering Committee (APLSC) internal meeting to solicit feedback, and is being presented via telecon on Friday 15 June.
 - Testing of the inverse solver is underway using a non-constant thickness BOLT geometry (i.e. relax requirement for constant thickness and allow simplified inner contour which is desirable for machining).
 - Making comparisons to 3D data being computed at the University of Minnesota
 - Modeling "heat streaks" between virtual "sensors" and building a sensitivity database to help inform on possible number and locations of sensors
 - We obtained HIFIRE-5B flight data from Tom Juliano at $x=400\text{mm}$ and will be testing the 2D inverse solver using the actual flight data, and comparing against the previously-computed heat fluxes from the 1D inverse methodology
 - Ground Testing
 - NASA Langley
 - The fabrication of the sting for NASA was on hold pending a full review of the sting by the NASA safety head. APL FEA modeling showed a stress concentration near the surface of the final thread in the threaded rod sting, resulting in a safety factor of 2 using maximum pitot pressure "unstart" loading. This was not anything that could be designed around without modifying the model and risking larger delays.
 - Held telecon with NASA Safety Head and obtained approval to build the sting but reduce the maximum stagnation pressure limit during testing (previous analyses was for $8\text{e}6/\text{ft}$ Reynolds number which is much higher than desired for this test). Performed new FEA analyses and identified a lower stagnation pressure to meet the safety factor 4.0 or 3.5 limit. 337 psia will meet the 3.5 safety factor and is acceptable for Langley. This is approximately a Reynolds number of $\sim 5.5\text{e}6/\text{ft}$ which is already nearly fully turbulent for BOLT based on previous data.

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- Sting was submitted to shop and a favor pulled... built in less than 24 hours, due to arrive at Langley on Monday
 - Model is at Langley getting some fiducial marks added and they are swapping in 2 Schmidt Boelter gauges (one on PEEK side, one on Aluminum side in symmetric location)
 - Ordered materials to test out gluing large roughness strips onto PEEK and remove them without damaging surface
 - Shipped more materials to Langley
 - Heather Kostak is working to see if the TAMU code for IR FLIR camera might work for analyzing Langley's data
 - CUBRC
 - Interpolated CFD-based heat flux onto CUBRC TSP data files for main surface to plot "transition fronts"
 - Working to interpolate gutter TSP transition fronts, using gutter TSP files sent by CUBRC this week
 - Packaged "final" raw CUBRC data to SharePoint site:
https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Ground%20Testing/2018-02%20CUBRC%20APL%20Test/_FINAL_DATAPACKAGE
 - Post-processed data will be added in the future
 - Purdue
 - Heather Kostak is working with Josh Edelman at Purdue to process IR images for heat transfer
 - Texas A&M
 - Heather submitted abstract for TAMU ground testing paper for SciTech 2019

6/16/2018 through 6/29/2018

- Upcoming dates/milestones:
 - 6/28/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 7/13/18 - BOLT Flight Planning Telecon (topic: discussion of thermal modeling and choice of aluminum)
 - 8/27/18 to 9/7/18 - (pushed back from July 2018) current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Flight Geometry Instrumentation
 - John Thome presented progress on developing inverse heat transfer solution methods for predicting heat flux in flight from the Medtherms on 6/15/18

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- Attendees - Schneider, Johnston, Candler, Borg, Adamczak, TAMU stability team, Wadhams, Bowersox (Brad mistakenly did not include Ivett on the invite...)
 - Link to slides:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2018-06-15-thermal-inverse-solver-update.pptx?Web=1>
 - Schneider raised possibility of including some sensors in depth for flight... needs to be considered
 - Schneider recommended textbook reference "Inverse Heat Conduction" by Blackwell et al. Ordered and given to John Thome as a reference this summer.
 - After meeting, APL reached out to Adam Amar and group at NASA Johnson and a technical discussion is planned to learn their experiences with inverse solver methods
 - APL team met with AEDC Tunnel 9 on Tuesday 6/19 to discuss their experiences with Medtherms
 - Received info on quality checks on Medtherms, including specific procedures
 - Info on calibration of sensors (linear interpolation of NIST tables vs curve fits). Tunnel 9 prefers the linear interpolation route.
 - T9 sent their version of QCALC which includes capabilities for temperature-dependent thermal properties
 - T9 recommends that TPRL, Inc. can measure thermal properties of actual material that we use to build BOLT Flight Geometry. Sent request to TPRL for quote for a similar report but have not yet heard back.
 - Discussed T9 hole tolerances for Medtherms - Loctite vs. press fit considerations, etc.
 - Discussion on inverse 2D solver
 - Still need to analyze pressure sensor expected measurement ranges for flight, used to record mean pressure for accurate attitude determination
 - Heather Kostak will be working this while at APL this summer
 - Provided existing CART3D surface pressure data to Heather
 - CUBRC model left APL for TAMU on 6/19
 - BOLT at AIAA AVIATION 2018
 - Four papers were presented at the BOLT session at AIAA (Brad, Dennis, John Thome, and Alex Moyes)
 - Brad Wheaton held meeting with entire TAMU stability team to discuss future analyses
 - Besides ongoing work on NPSE and biglobal stability analysis methods, requested quantifiable data that could be used for determining regions on the

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- flight geometry where instrumentation should be clustered (e.g. spanwise distributions of N-factors at various axial locations, etc)
 - Also asked if TAMU stability team can suggest some roughness concepts for the Purdue experiment, to trigger crossflow modes for instance
 - John Thome provided BOLT mean flows to TAMU and to Neal Bitter from Sandia for biglobal analyses
 - Scott Berry briefed NASA Langley PEEK model roughness results. The transition location was relatively unaffected by distributed roughness added off the leading edge, although there was some movement for the highest roughness tested.
 - Brad Wheaton met with Graham and John Thome to discuss Minnesota thermal modeling comparisons and plan for presenting at 7/13 telecon
 - Ground Testing
 - NASA Langley
 - After various issues with broken sensor connections, grounded sensors, and air supply maintenance, the NASA test began on Thursday 6/28
 - The smooth-wall Reynolds number sweep was completed on the first day of testing. Transition onset begins at $Re \sim 1e6$ in noisy flow measurements at LaRC
 - Dennis is supporting this week and Dennis/Heather will be on site next week
 - The plan is that NASA may run extra shifts to complete the test by 7/10 within the original window, due to air supply availability during the first portion of the window

6/30/2018 through 7/6/2018

- Hope everyone had a great 4th of July holiday!
- Upcoming dates/milestones:
 - 6/28/18 to 7/10/18 - current NASA Langley 20-Inch M6 entry window
 - 7/13/18 - BOLT Flight Planning Telecon (topic: discussion of thermal modeling and choice of aluminum)
 - 8/27/18 to 9/7/18 - (pushed back from July 2018) current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Held telecon with NASA Johnson (Amar et al.) on 3 July to discuss Inverse Heat Transfer Methods
 - JSC: Adam Amar, Brandon Oliver, Giovanni Salazar, Justin Cooper
 - Briefed John Thome's status of inverse 2D analyses for BOLT, and upcoming work including HIFIRE-5B analysis with same method
 - JSC group feedback:

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- Our problem is luckily easier than traditional inverse methods which deal with ablation and entirely subsurface temperature measurements
 - Unknown how will Medtherms perform with a high lateral temperature gradient... suggested some quick look analyses
 - Said this isn't really a "true" inverse analysis because enough of the boundary condition is being measured, but it still is challenging
 - Temperature-dependent properties will be very important to get correct. They like our plan to get samples characterized by TPRL.
 - Noise from the sensor will also be a critical challenge. They think we will learn much from analyzing the HIFiRE-5B data.
 - Thermal Analysis
 - On 3 July we were shown preliminary Minnesota thermal results (for fully turbulent descent) that showed considerable discrepancies with the predicted maximum temperatures at 488.0s. We are currently working with Minnesota to fully scrub our results and their results ahead of the 13 July telecon.
 - Creating a 3D point matched thermal grid to the APL CFD grid in order to use a third code (CFD++) to check against the APL MSLRAD and Minnesota US3D temperatures.
 - Ground Testing
 - NASA Langley subscale model testing
 - 45 runs completed as of 7/3
 - Roughness joint simulation results in minimal apparent movement of transition but does seem to amplifying heating of vortices
 - 6 hours of test time remaining, one day next week possible unless air system maintenance causes slip beyond test window end date of 10 July
 - NASA Langley ceramic model testing
 - We have an additional ceramic model test available in our Space Act Agreement with NASA Langley, and need to decide what to test. We have enough data on the Flight Geometry and are thinking of having NASA test the Flight Geometry plus a portion of the Payload System (Transition Module). This test could examine heating from an unshrouded Flight Geometry.
 - CFD/Stability
 - Texas A&M (Alex Moyes) is analyzing Purdue mean flows to suggest potential roughness experiments for the final subscale model entry. He is also providing traveling crossflow N-factors.
 - Running NASA Langley mean flows for roughness correlations of tested trip heights, and to enable calculation of stability results at Langley conditions.
 - VirtusAero has reported completion of STABL-3D analyses but we are waiting on the data to be delivered.

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- Inquired about status of AFRL/RQ CFD analysis by Ryan Gosse of vortex shedding from the BOLT Flight Geometry, as Ryan is leaving later this month for a new position at Raytheon.

7/7/2018 through 7/20/2018

- Upcoming dates/milestones:
 - 7/27/18 - BOLT Flight Planning Telecon (topic: follow up to discussion of thermal modeling and choice of aluminum)
 - Mid August - finalize types and gains of instrumentation for Sensor Collection Board order
 - 8/27/18 to 9/7/18 - (pushed back from July 2018) current Purdue subscale entry #2
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Thermal modeling telecon held 13 July 2018
 - Purpose: review all existing thermal modeling work since CoDR
 - APL attendees: Wheaton, Berridge, Thome, D'Alessio, Trent Taylor, Brian McGrath, Ryan Stevens
 - External attendees: Leyva, Schneider, Bowersox, Reed group, Dolvin, Adamczak, Candler, Borg
 - Slides posted at <https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2018-07-13-thermal-modeling-telecon-v03.pptx>
 - Telecon discussion points and action items:
 - Steve Schneider requested CUBRC review intermittency of the thin films on the swept leading edge, as an additional verification that they are truly laminar. Sent request to CUBRC Monday 16 July to review these data.
 - Dave Adamczak reported some aluminum sensors on HIFiRE-5B exceeded 400C in a few sensors, after the end of experiment but while data were still transmitting.
 - Need to run AoA/yaw sweep to predict at what orientation pressure loading is maximized, and whether 0deg heating is truly an "average" heating value seen at the swept leading edge.
 - Steve S. requested APL proceed with some quick "back of the envelope" analyses prior to next telecon on 27 July, looking at approximate stress from notional pressure loads
 - Discussion about end of experiment (477.2s vs 488.0s). Questions asked about what is Reynolds number factor between transition in conventional tunnels vs.

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- flight? BOLT transitions at $Re_L=1e6$ in noisy tunnels. At CUBRC $Re_L=4e6$ was about mid-point on the geometry. Bowersox cited some HF1 and HF5 data showing some factors in transition Reynolds number between flight and ground data.
- Matt Borg also pointed out after the telecon that if transition occurs much later in descent, it would also result in much lower temperatures than modeled in the "tripped" thermal case, so that probably helps a lot.
 - Plan is to reconvene on 27 July with updates and resume discussion
- Thermal modeling internal meeting held 18 July with APL Steering Committee (APLSC)
 - Some quick look analyses discussed
 - Pursue NASTRAN quick look static analysis on existing thermal grid, perhaps available before 7/27 call
 - Thermal and structural modeling
 - Basic structural model of axial cut of aluminum
 - Applied aero loads for 488s, $\alpha=4$, and $\beta=4$. No appreciable change to maximum stress. Majority of stress appears to be from thermal growth.
 - Dave Adamczak provided notional α/β excursions to APL for correlation-based run with thermal grid
 - Used HF5 6DOF model and scaled it to reduce stability to be more like BOLT
 - 6DOF model without excursions ended up with very low α/β
 - Dave scaled output to be more representative of that seen in other flights
 - Provided α/β trajectory to Ryan Stevens to run correlation based model when able
 - CFD++ laminar model to compare against MSLRAD tripped model
 - Maximum temperature for fully laminar descent is about 50K lower than tripped descent
 - Interface with AFRL/RQ towards ordering sensor boards
 - Sensor boards need to be ordered by late August due to expiring funding
 - Will need to know thermocouple types and gains, as well as number of sensors
 - Plans to increase # Medtherms... need to scrub latest quotes, budget
 - Using new 24bit A/D converters compared to previous 12bit A/D converters... may be able to set max temperature much higher and still have significantly improved resolution
 - Will need to know Vatel max heat flux
 - Working to set up routine calls btw. APL and RQ to finalize details in August
 - Dave out July 20-30
 - Brad out July 28-Aug 3
 - Ground Testing
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- NASA Langley
 - Completed the NASA Langley test on Friday. Heather Kostak and Greg McKiernan ran the test for the last day, testing joint tolerances for a separate leading edge piece, in case that design was necessary. Overall test was 51 runs, with 10 different roughness configurations tested and a Reynolds number sweep. Very early assessments suggest that joints at least 0.010" should be tolerable without altering the transition location, though there are noticeable changes to the flow field. Post-processing is now under way.
 - The model will be returned to APL from NASA Langley next week
 - Heather Kostak has completed work on scripts to convert the IR results to heat transfer for Purdue and NASA. Work is now underway to do the conversions.
 - Purdue
 - Desired parameter values for crossflow-control roughness inserts for the final Purdue test have been determined after looking at previous experimental results, DNS from Minnesota, and instability computations at Texas A&M
 - Hardware design for inserts is underway
 - Baseline plan is for 5 inserts, with amount potentially altered after costs are identified
 - CFD and Stability
 - Extracted NASA Langley condition roughness correlations from mean flows
 - Mirrored existing CFD++ mesh and conducting a roll sweep at $\alpha T = 5$ degrees to look at off-nominal heating on the swept leading edges. These cases would have finished by now but we are experiencing some problems on our new cluster that we are working to debug.

7/20/2018 through 7/27/2018

- Upcoming dates/milestones:
 - 7/27/18 - BOLT Flight Planning Telecon (topic: follow up to discussion of thermal modeling and choice of aluminum)
 - Mid August - finalize types and gains of instrumentation for Sensor Collection Board order
 - 8/27/18 to 8/31/18 - current Purdue subscale entry #2, reduced to one week
 - 9/1/18 - BOLT flight instrumentation data delivery deadline
 - 9/10/18 to 9/11/18 - pre-PDR meeting in Arlington VA
 - November 2018 - potential trip to Esrange Sweden
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status

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- DLR is under contract!
 - DLR received their grant award on 19 July.
 - Telecon with DLR occurred on 24 July
 - DLR is working on proposal modification to add funding for the ACS system
 - Schedule for PDR will be worked by APL pending a re-baselining of the overall schedule btw. APL and AFRL/RQ
 - BOLT Data Call for Flight Instrumentation (1 September deadline)
 - APL sent out a request for datasets from the team that can be used to select and place flight instrumentation
 - Examples are CFD and stability parameters, processed wind tunnel data
 - The deadline for sending your contributions is 1 September! Send whatever you have by then that can be useful!
 - Sensor Collection Board order
 - AFRL/RQ needs to order the SCB's by end of August, requiring instrumentation details from APL due approximately mid-August
 - APL and AFRL/RQ scheduled to talk multiple times per week to resolve details of this order
 - The major decisions are:
 - Type of thermocouple (Type T for Aluminum!)... hopefully resolved with choice of aluminum
 - Number of TC's we wish to allocate to the Stainless Steel mid section (Type E)
 - Gains are also needed but can be changed later in the boards (not ideal).
 - We will likely be able to estimate gains to 1st order for the thermocouples based on our thermal model plus 30% margin on max temperature.
 - Kulites are all 0.1V max output regardless
 - However, Vatecs need heat flux ranges and that will not be known with certainty by August (we haven't determined where the Vatecs will be placed)
 - Thermal modeling
 - CUBRC examined thin film fluctuation histories for the cases that were run in Spring 2018, which was an action item from the 13 July call (do time histories agree with mean heating levels that flow is laminar on swept leading edges). CUBRC looked at the data and agrees that it is a "strong bet" that the leading edge remains laminar on this shape.
 - Structural Modeling
 - Structural modeling results to be presented at telecon on 27 July, where intent is to gather consensus to proceed forward with Aluminum as the aft component material.
 - Solidworks simplified stress analyses were run for only an axial "slice" of aluminum. These were quick look analyses with room-temperature properties and manually input heating and pressure distributions.

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- Quick look showed aerodynamic loads negligible effect on peak thermal stresses, for $\alpha=4$ and $\beta=4$ at 488.0s
 - Thermal stress estimates from axial expansion characterized for ascent peak temperature and descent 488.0s
 - NASTRAN 3D transient thermal analysis was run as a high fidelity check (ascent only)
 - Results showed for the "tripped + 25%" heating that HIFiRE safety factors on yield stress are maintained through the end of ascent
 - Simplified linear expansion model used to estimate transient stress for entire trajectory
 - Based on differential expansion (linear only) between T_{bulk} and T_{max} in Aluminum
 - Due to conservatism of this model (not allowing transverse expansion) the temperatures from the tripped heating model without 25% margin were used
 - Linear expansion model overpredicts peak stress relative to NASTRAN 3D high fidelity stress, but agreement is fairly close otherwise
 - The linear expansion model predicts yield stress is only reached on descent at approximate $Re_L=15e6$
 - CFD and Stability
 - John Thome compared US3D turbulent heating to CFD++ turbulent heating for a descent case (Mach 7.2, $Re_L=2.5e6$) and found very good agreement. CFD++ had slightly higher turbulent heat flux on the swept leading edge but only by about 3-6%.
 - John Thome ran a roll sweep at total angle of attack of 5 degrees to compare the average heating on BOLT to the heating at 0-deg AoA/yaw. The cases were run at Mach 7.2, $Re_L=5e6$ (483.8s Woomera time) with laminar heating. The averaged heating on the body is comparable to the 0-deg heating, with slightly less heating observed on the swept leading edge (because the heating peak moves during the rolling of the stack). At the aft end of the body, some higher average heating was observed but only in the centerline of the main and gutter surfaces where temperatures are not critical.
 - AFRL/RQ continues to run CFD to look at fairing designs on the booster stack. Ryan Gosse handed off the work to Nick Bisek and Tim Leger.
 - Ground Testing
 - Planning of the next NASA Langley ceramic test is on hold pending discussion of AFRL/RQ fairing CFD results. One idea for the final LARC ceramic test was to look at heating and/or oil flow on the Flight Geometry plus TSM/PSM sections of the stack, with and without fairings.
 - The Purdue final entry has been shortened to one week at the end of August. The entry will focus on obtaining sensor measurements with the final suite of instrumentation, measuring heating at higher quiet pressures than previously obtained, and testing several roughness configurations.
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7/28/2018 through 8/10/2018

- Upcoming dates/milestones:
 - 8/27/18 to 8/31/18 - current Purdue subscale entry #2, reduced to one week
 - 9/1/18 - BOLT flight instrumentation data delivery deadline
 - 9/10/18 to 9/11/18 - pre-PDR meeting in Arlington VA
 - 11/14/18 to 11/18/18 - AFRL/RQ, AFOSR, and APL trip to Esrange Sweden
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Working out new overall schedule
 - Working out new master schedule, to include Flight Geometry PDR and CDR
 - AFRL/RQ reaching out to DLR about desired delivery of integrated payload
 - A notional target date to provide AFRL/RQ with the instrumented Flight Geometry would be May 2019, but this is still being discussed by both organizations
 - The original CoDR schedule called for delivery of the Flight Geometry to AFRL/RQ in March 2019 ahead of a December 2019 flight test (9 months prior to flight). A May 2019 would give extra margin for testing activities at RQ with a ~12 month lead time, or give extra margin for difficulties fabricating or installing instrumentation.
 - Due to APL spend rates, it is likely we may need to have our Flight Geometry CDR at the end of Calendar Year 2018 or in early January 2020 based on current spend rates. Any later and we risk leaving insufficient budget margin available for fabrication and instrumentation. This is still being discussed.
 - The above constraint would potentially leave pre-PDR, PDR, and CDR for the Flight Geometry in a short period. It is unknown if we will be able to sync PDR and CDR with DLR due to timing of the ACS system funding
 - APL suggested that DLR could at least provide an update ASCENT trajectory ahead of PDR, even if the details of the ACS are not yet worked out for descent. This would allow updated ascent thermal modeling, potentially with excursions, for ascent.
- Purchase of new Sensor Collection Boards
 - AFRL/RQ got extension on contract allowing a delay in purchase of the Sensor Collection Boards from August 2018 to November 2018.
 - APL requests increase of number of Medtherm gauges from 100 to 116 or 120 (exact amount depends on number of free channels currently existing. The increase is desired to increase resolution of temperature distributions to support flight data analysis methods (inverse 2D). The increase will require purchase of one extra Sensor Collection Board and Digital Signal Processor than originally planned.

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- Dave confirmed that the A/D converter bit rate is 24-bit vertical resolution, however the data are put into the TM stream at 16 bit. Some data can be sent back at 24-bit if desired, but not many channels. This resolution is higher than in previous HIFiRE flights (12 bit).
 - Flight Instrumentation
 - APL to proceed ordering Kulites and hopefully Medtherms this month
 - Low-frequency Kulites for static pressure
 - AFRL/RQ provided APL with part numbers and specs for XCEL-100-15A sensors, to be used for static pressure measurements to determine BOLT angle of attack and yaw
 - Obtained quote from Kulite for XCEL-100-15A sensors with:
 - "Miniature High Temperature Pressure Probe supplied with 6 inches of 36 AWG cable between probe and compensation module, 24 inches of 32 AWG cable¹ from compensation module to pigtails for customer connection, shield of cable to be carried through compensation module."
 - Quoted price \$1122/sensor. 16 sensors planned for flight. APL will likely order 20 to have a few spares.
 - Heather Kostak has been looking at inviscid aerodynamic data to ensure 15-psia diaphragm is proper choice. Seems to be the best choice.
 - Medium-frequency Kulites
 - Kulite no longer offers the XCEL-100-5A sensor
 - Medtherms
 - Planning to increase # of Medtherms from 100 to 116 or 120.
 - We are proceeding with Aluminum as the aft component material. Thus, the majority of the Medtherms will be Type T. However, we will need to provide AFRL/RQ with the number of Medtherms planned to be placed in the Steel mid section. Those will be Type E. An SCB CAN consist of a mix of Type T and E TC's.
 - Vatel heat flux gauges
 - Quoted lead time was 4 weeks, least of all sensors, so have not focused on researching these yet. The range of these sensors also depends heavily on the instrumentation layout (where they are to be placed).
 - Ground Testing
 - Purdue
 - Encountered difficulties matching the contour of the BOLT subscale model when the roughness inserts were being machined. The contour was not matching the theoretical CAD geometry. Eventually a fix was found and the parts were machined, but the reason for the discrepancy is not known.
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- APL will do a detailed inspection of the subscale model following completion of testing so that we can determine lessons learned before fabrication of the flight hardware.
 - Texas A&M
 - Making arrangements to send subscale model to TAMU following completion of Purdue testing
 - Will also loan TAMU all Kulites and PCB's from APL
 - CFD/Stability
 - Received final STABL-3D data from VirtusAero on 27 July 2018

8/11/2018 through 8/17/2018

- Upcoming dates/milestones:
 - 8/27/18 to 8/31/18 - current Purdue subscale entry #2, reduced to one week
 - 9/1/18 - BOLT flight instrumentation data delivery deadline
 - 9/10/18 to 9/11/18 - pre-PDR meeting in Arlington VA
 - 11/14/18 to 11/18/18 - AFRL/RQ, AFOSR, and APL trip to Esrange Sweden
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- Working out new overall schedule
- Flight Instrumentation
 - APL to proceed ordering Kulites and hopefully Medtherms this month
 - Worked out new budget for sensors including flight sensors and spares
 - Kulites
 - Kulite agreed to offer XCEL-100-5A sensor in the "old" design used for high-frequency pressure fluctuation measurements
 - Obtained final draft Kulite quotes for XCEL-100-15A and -5A sensors
 - Ran Heather Kostak's MATLAB code to look at expected pressure ranges and variations in flight
 - Created time-history of mean main surface pressures using oblique shock wedge flow approximation
 - Created slides documenting expected pressures in flight
 - Medtherms
 - Reached out to Medtherm for telecon on available options, awaiting response
 - Plan is to order all sensors "long", but hope to save costs if some sensors can be shortened
- Mechanical Design and Thermal Analyses

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- One last thermal analysis is being performed before the detailed PDR design efforts spool up: variation of TZM length (quick look accomplished by breaking the existing grid at several grid lines).
 - We are seeking data to see if we can move the TZM/stainless interface farther upstream (shorten the TZM piece and lengthen the Stainless piece). The aluminum/stainless interface. The reason to shorten the TZM piece is to save costs on the Iridium coating.
 - Ground Testing
 - Working on final report! Document to include summaries of all tests, key findings, etc. All data to be packaged and made available (CUBRC data is already packaged and on SharePoint).
 - Purdue
 - Roughness inserts completed (6 total, 5 with cylindrical press fit rods)
 - First two inserts have elements with height of 0.015" spaced at: 0.14", 0.16"
 - The next three are all spaced at 0.16", and have heights of 0.005", 0.010", 0.020".
 - The diameters are always 0.040".
 - The last insert was sandblasted, but the resulting roughness is way too smooth and we didn't pursue changing it further.
 - Greg McKiernan will drive the subscale model from APL to Purdue when he returns this weekend (thanks Greg!) and may also be picking up Matt Borg's IR camera from Dayton (thanks Matt!)

8/18/2018 through 8/31/2018

- Upcoming dates/milestones:
 - 9/1/18 - BOLT flight instrumentation data delivery deadline
 - 9/10/18 to 9/11/18 - pre-PDR meeting (determination of logistics and location is in progress)
 - 11/14/18 to 11/18/18 - AFRL/RQ, AFOSR, and APL trip to Esrange Sweden
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - TBD - Preliminary Design Review (PDR), delayed from July 2018 due to DLR contract status
 - TBD - Critical Design Review (CDR), delayed from September 2018 due to DLR contract status
- BOLT Data Delivery Deadline (9/1)
 - Received flight stability data from Alex Moyes
- Flight Instrumentation
 - Held telecons on 8/17/18 and 8/24/18 to discuss instrumentation types and options
 - Roger Kimmel provided an overview summary of measurements from HF1 and HF5B

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- Decided first order of flight Kulites (Qty 16 of the XCEL-100-15A sensor and Qty 24 of the XCEL-100-5A sensor).
 - Mechanical Design and Thermal Analyses
 - Report documenting new thermal analysis with a shortened TZM nosetip have been provided. The effect on peak TZM and Stainless Steel temperature is minimal when moving the TZM/SS joint farther upstream. However, movement of the joint farther upstream may create more concerns about roughness.
 - Received new quote from Ultramet for Iridium coating. The difference between the nominal nosetip coating (\$40K) and a shorter nosetip coating (\$30K) is only \$10K, so it seems the cost savings may not be worth the risk of moving the joint farther upstream from nominal.
 - The Ultramet coating cost for the actual part is also significantly lower than originally budgeted \$85K, which is great news. That money will be held in reserve for now in case there is a problem with the part and a new coating needs to be purchased down the road.
 - Completed a revised mechanical design concept for the Flight Geometry and currently meeting with APL machine shop to discuss feasibility and detailed manufacturing considerations
 - Ground Testing
 - Purdue
 - We have been conducting the final APL Purdue entry with the subscale model
 - The model is heavily instrumented and setup time was long. There are over 40 channels of data being recorded, including 18 PCB's and 14 Kulites, as well as TSP and IR imaging
 - We are testing at or near a maximum quiet pressure of 155 psia, which is about 20% higher performance than in the previous entries. The entry is focused on high-quality measurements from sensors to detect potential instabilities at selected conditions at maximum quiet pressure.
 - We do not observe transition under quiet flow, however we are seeing many potential peaks in the spectra that may be instabilities
 - We initially thought we were observing transition under quiet flow at 4-deg angle of attack, however investigation discovered the nosetip was slightly misaligned resulting in a 0.005" forward facing step at the swept leading edge on one side of the model, and a 0.005" rearward facing step on the other side. Correction of the nosetip eliminated the transition front being observed. Runs were repeated with the corrected nosetip.
 - A series of tests with the spanwise arrays of roughnesses were also conducted under quiet flow. The roughness array height was varied and transition movement was observed from completely laminar to nearly effective. A series
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of streamwise streaks were created by the array but it remains to be seen if these streaks occur solely due to the roughness array or if they are augmentation of existing streaks seen under the nominally smooth case.

9/1/2018 through 9/28/2018

- Upcoming dates/milestones:
 - 9/28/2018 - freeze numbers and types of Medtherms, Vatellets, and Kulites
 - 10/29/2018 - PDR Science Team Instrumentation Layout Review meeting
 - 10/30/2018 - Preliminary Design Review (PDR) for Science and Payload System
 - 11/14/18 to 11/18/18 - AFRL/RQ, AFOSR, and APL trip to Esrange Sweden
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - TBD - Critical Design Review (CDR),
- Schedule
 - Further defined schedule with respect to setting PDR and CDR start dates, but also fabrication and instrumentation of the Flight Geometry
 - Scheduled date for PDR - October 29 and 30, 2018
 - October 29 will be a meeting for just the core science team to review progress made towards a flight instrumentation layout. It will be held either at APL or at the BRICC in Arlington VA
 - October 30 will be PDR, held at the BRICC in Arlington VA
 - Targeting date for CDR NLT late January
- Pre-PDR Meeting was held at APL with AFRL/RQ (9/10/18 and 9/11/18)
 - APL and AFRL/RQ met all day on 9/10/18
 - APL: Wheaton, Wolf, D'Alessio
 - RQ: Dolvin, Adamczak, Johnston, Kimmel, Tancred
 - Summary slides available at <https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2018-09-10-BOLT-PrePDR-Day2update.pptx?Web=1>
 - Further defined some PDR expectations on Day 2 with Leyva, Norris. Bowersox also attended.
- Mechanical and Thermal Design
 - New Flight Geometry design presented at pre-PDR
 - Aluminum frustrum is now two parts with clamshell interface at gutter centerline. Reduces number of parts for frustrum from 4 to 2. Marman clamp concept to join parts at gutter.
 - New design removes interior structure inside Flight Geometry. More room for SCB's and instrumentation, saves weight. There were concerns about cold interior structure stresses with hot outer material.

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- Joint design
 - A proposed joint design was shown at pre-PDR meeting in September with a concept for overlap to potentially reduce and control steps at joints from thermal expansion. However constraining material will introduce some extra stresses. Can be mitigated with filleting and chamfering at interior corners.
 - AFOSR requested analyses to determine expected joint mismatch in flight.
 - A simple/conservative linear thermal expansion analysis of both joints was performed by Wheaton
 - Indicated growth mismatch of approximately 6-7 thou for the TZM/SS joint and 4-6 thou for the SS/Aluminum joint.
 - The assumptions made were constant bulk temperature at the joint interface (bulk temperature estimated from previous thermal analyses at Woomera flight conditions, without 25% HTC margin). Room temperature (constant) CTE properties were used. The length of material used for the linear expansion estimate was the worst-case distance from the centerline of the body, at each joint.
 - APL is also running a simplified FEA analysis to determine feasibility of joint concept from a structural standpoint, and estimated step heights for sizing cold-wall steps
 - These FEA analyses use models of the joint geometries but do not incorporate the full transient thermal distribution, as that distribution is difficult to implement and will be part of the "final" transient thermal structural analysis at CDR.
 - These models are showing the worst case step is likely right on the swept leading edge
 - Method 1: initialized FEA models to estimated/constant bulk temperature at the joint, using same temperatures from above simple analysis
 - Upstream joint (TZM/SS, $\Delta T = 180K$ for ascent, $210K$ for descent): 0.0036" at end of ascent and 0.0042" at end of experiment
 - Downstream joint (SS/AL, $\Delta T = 140K$ for ascent, $190K$ for descent): 0.0030" at end of ascent and 0.0042" at end of descent
 - Working on Method 2: Used heat flux distribution to approximate thermal distribution by matching maximum temperatures at the joint
 - Working to calculate Re_k from ground test roughness experiments, and extrapolate to allowable roughness for flight cases

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- At PDR we will present our proposed concept for the joint design, with backup plan identified and steps to close on design.
 - Aerodynamic Fairing
 - Concerns about lack of closure on the aerodynamic fairing issue were discussed in detail at the pre-PDR meeting
 - AFRL/RQ and APL established a plan to close on the fairing design by PDR, however just after the meeting a potential issue with range apogee was discovered that may drastically affect weight and thus stability. Regardless, a new fairing design iteration is being performed.
 - The first initial fairing concept had a length of 3.5" and an expansion angle at the swept leading edge of approximately 23 degrees maximum from main surface and 60 degrees with respect to the aft leading edge contour.
 - Per Roger Kimmel the turning angle of the HIFIRE 5B "transition section" was about 17.6 degrees.
 - RQ and APL created new longer fairing concepts with reduced fairing angles. APL produced a concept approximately 7" long and RQ approximately 9.5" long.
 - APL and RQ recommended that their fairing concepts be evaluated aerodynamically, and chose Fairing designs B and D. Fairing B is a straight edge expansion of 30 degrees from the swept leading edge, and about 13 degrees from the main surface. Fairing D has a much reduced curvature at the swept leading edge.
 - Fairing B was sent to Minnesota for evaluation with CFD, to determine potential effects on the experiment. Fairing B was sent because it had the worst case turning angle of the two new designs.
 - RQ is finishing the initial aerodynamic analysis of both Fairings B and D and expects results early next week (beg. of October).
 - Flight Instrumentation
 - 16 15-psi Kulites and 24 5-psi Kulites were ordered by JHU/APL on 9/5 for a total of \$50K and the requisition was completed on 9/14.
 - BOLT data delivery was completed in early September and the results were presented to the team for comment on data sources on September 14.
 - On September 21, instrumentation Version 02 incorporating new data was released to the team for review and feedback.
 - Feedback is being tracked in a master spreadsheet to ensure that all comments are evaluated properly and taken into account during subsequent layout updates.
 - On September 28, Instrumentation Version 03 will be sent to the team.
 - The major instrumentation changes are as follows:
 - Increased Kulites sampled at medium-frequencies from 8 at CoDR to 32
 - Increased Vateils from 6 to 16

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- Reduced Medtherm count slightly to nearly 112
 - The increased number of instruments has been matched with budget by reducing the number of spares

9/29/2018 through 10/19/2018

- Upcoming dates/milestones:
 - 10/29/2018 - PDR Science Team Instrumentation Layout Review meeting
 - 10/30/2018 - Preliminary Design Review (PDR) for Science and Payload System
 - 11/14/18 to 11/18/18 - AFRL/RQ, AFOSR, and APL trip to Esrange Sweden
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - TBD - Critical Design Review (CDR)
- Secondary (Roughness) Experiment
 - Scott Berry to coordinate planning and design of secondary roughness experiment
 - Allocation of 24 Medtherms has been assigned to the secondary experiment side, and 12 Kulites moved back to primary experiment side. The 24 Medtherms use only 2 sensor collection boards, so only 8 total backface measurements obtained in favor of additional surface locations.
- Instrumentation and Layout
 - Layout and update revisions documented in slides since 9/29: v04 (10/09) and v05 (10/15)
 - Increased Medtherm sensor count to accommodate secondary experiment and by selectively using front-face only sensors at certain locations (nominally + 32 physical sensors)
 - Selected number of nosetip and joint thermocouples (2 type K nosetip and 6 type K joint TC's)
 - Placed extra Kulite order (+16 -5A's)
 - Confirmed custom specs on two Medtherm variants (11586 and 10607) from RQ. 11586 has a backstop and will be used for interior installs on the nearly constant-thickness acreage. 10607 can be installed from the front or rear and will be used for challenging installation locations on the swept leading edge, and for the steel isolator installs. Working on counting different lengths to provide Medtherm with part numbers for a quote and order in the immediate future.
- GHI HIFLIER 1 PDR
 - APL attended HIFLIER 1 PDR on 10/18/18 to see progress on PCB flight qualification and data system design
 - To work with GHI and RQ what details are able to be shared due to proprietary concerns, likely execute NDA with GHI to address
 - Key takeaways for immediate relevance to BOLT:

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- PCB survivability and heat sink design is being optimized for a different flight and geometry (cone) and thus far is not being analyzed for BOLT. It seems likely with BOLT's lower temperatures we could have enhanced survivability but remains uncertain, and there are limited plans to evaluate for BOLT. Plan will be to use existing design for BOLT.
 - Some risk of surface roughness near end of flight from sensor RTV char --> will want to move upstream PCB farther aft to minimize effects on other sensors. Risk of surface roughness from PCBs on Quadrant B should be considered when evaluating instrumentation layout on that side.
 - Joint step roughness
 - Summaries of wind-tunnel data to be provided at PDR:
 - CUBRC trips were all too large (effective) and were not realistic simulations of joint expansion since their goal was to trip the swept LE attachment line
 - NASA Langley trip data obtained, but difficult to determine in IR data if the trips induced laminar augmentation of heat streaks or if the streaks transitioned. Langley data did seem to indicate that downstream trip could be more critical than upstream trip, when equal size trips were used. Langley trips were also relatively high Re_k
 - Best trip data point seems to be Purdue nosetip misalignment data, but just one case obtained. Data did show that equivalent height forward facing step induced transition when backward facing step did not. CFD performed by APL calculates Re_k for the observed Purdue case and is scaled to flight conditions for determining step height tolerances
 - Fabrication plan to artificially lengthen each part and machine down to size presented in telecon on 10/12 and will be shown at PDR
 - Definition of critical joint evaluation locations will be shown at PDR. Tolerance will be enforced at that location and remaining step heights will dependent on sizing of critical location. Details to be shown at PDR.
 - Critical Path and Schedule
 - Defined critical path and schedule from now until delivery of instrumented Flight Geometry to RQ, notionally in June/July timeframe.
 - Key uncertainties in the critical path and schedule are the Medtherm delivery timeframe (4 to 6 months) and determination of need and timing for a structural bend test (DLR may not require)
 - Sensor Boards
 - Extension of deadline to 21 November gives a little more flexibility before finalizing
 - Provided nominal gains to Dave Adamczak for all sensors
 - Aerodynamic Fairing
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- RQ finished CART3D stability analyses of Fairings B and D
 - Fairing B stability offset is 13 kg of weight @ nosetip, APL is planning notional tungsten ballast to offset
 - Minnesota CFD identified shock/shock interaction at trailing edge of Fairing B and D, confirmed also in RQ CART3D solutions. Occurs due to compression where fairing meets TSM OML
 - APL designed blending Fairing concept (Fairing II) and provided to RQ and Minnesota
 - RQ to perform CART3D. Convergence of stability/weight/ballast will continue past PDR.
 - Fairing mechanical concept plan to be presented at PDR but is not critical path to remaining design
 - CFD/Stability
 - Minnesota Fairing CFD completed on Fairings B and D
 - Sandia BiGlobal results presented by Neal Bitter indicating potentially large N-factors in center vortex structure just off the centerline. Instrumentation moved
 - APL computed turbulent heat flux @ AoA for comparison of expected heating differentials between turbulent windward surface and laminar leeward surface to address concerns about Medtherm dynamic response

10/20/2018 through 11/9/2018

- Upcoming dates/milestones:
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - 11/29/2018 - Delivery of subscale model to Purdue for nosetip joint testing
 - TBD Late January - Critical Design Review (CDR)
- PDR held 10/29 and 10/30 in Arlington VA at the BRICC
 - PDR slides from both days posted:
 - 10/29:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/2018-10-29-Instrumentation-Team-Meeting>
 - 10/30:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/2018-10-30-Preliminary-Design-Review-PDR>
 - The government caucus summarized four focus areas:
 - FAIRING – Choose one configuration and run all relevant checks with it (aero stability, vortex shedding, potential for buffeting, ballast required, effect on experiment etc). If it looks good go with it. We thought the long configuration (B) so far offered the most advantages. Please correct us if we are wrong. The reason for the urgency is that Dave needs the configuration to provide aero data to DLR who can then come back and give us an updated trajectory. So this is in the critical path for a final trajectory.

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- **JOINT STEPS:** How do you know that the way you are fabricating the BOLT joints and the height chosen at initial time and during the test windows won't trip the flow? Can we do either high fidelity computations to vary the step height until we see an effect on the flow, or can we run tests? Secondary question: If we do end up tripping the flow, can we differentiate between that result and a natural transition from the flight data?
 - **ROUGHNESS:** for the roughness experiment, given the complicated flowfield, how do we choose where to put isolated roughness elements? What are we expecting and what can we learn from them given the overall complexity of the flow? It was suggested to look at studying roughness as defined by having a back facing step deliberately machined to cause transition or put distributed roughness close to the swept leading edges.
 - **BIGLOBAL:** who can do more biglobal analyses of BOLT
 - The team re-convened during telecon on Friday 11/2 and discussed action paths for addressing these items:
 - **FAIRING**
 - Dave to provide Fairing B aerodynamics initially to DLR, pending approval to share data (to be worked separately)
 - Minnesota will still evaluate the short (CoDR) fairing for separation on the experiment. They already have CAD.
 - RQ to check with Bisek re: any unsteady simulations. Doug and Brad discussed if unsteady sims are a critical path item, as is not typically done as a preflight analysis
 - Scott to try to push for earlier tunnel slot for fairing test, but regardless there will be good lessons learned from any entry pre-flight
 - **JOINT STEPS**
 - Joint step testing to be performed at Purdue in early December, to gather more data on what step height will trip the flow in quiet conditions
 - APL will manufacture the additional nosetips and has proceeded to parametrically size these tips using available data. APL will deliver nosetips to Purdue and model by 11/29
 - E-mail exchanges highly significant uncertainty in best correlations to use to scale the Purdue trip heights to flight conditions
 - Minnesota asked to look at doing some CFD, where they can examine scales of vortices as a first step, and perhaps eventually compute a series of rear-facing steps to identify modification of the mean flow (but NOT predict transition as this is unknown)

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- Unavoidable uncertainty on joint step needs to be made clear to upper management, as this has significant legacy in HIFiRE program, and there will continue to be uncertainty in what step height will trip flow in flight
 - Regarding "If we do end up tripping the flow, can we differentiate between that result and a natural transition from the flight data?," the team discussed the only way to truly know would be to use the secondary (roughness) experiment to evaluate off-nominal forward or rear-facing steps and measure in-situ transition to compare against the primary experiment.
 - Asked to document what we have done as a team, what HIFiRE has done, and document what we will do
 - **ROUGHNESS EXPERIMENT**
 - Team discussed almost unanimously using the secondary experiment to obtain data on steps that are either simulated joints or to use the actual joints as the flight experiment for roughness
 - Tradeoff between using the actual joints for these experiments vs. machining another step somewhere else on the body that is more controlled. The tradeoff is between highly controlled step, versus using the experiment to assess what we think is happening on the main surface
 - Scott Berry to lead through reasoning of how to achieve the best experiment
 - **BIGLOBAL**
 - TAMU is working on biglobal capability, will accelerate and use BOLT as test case
 - Pedro @ LaRC could be asked to do some analyses as well
 - Need to agree on a laminar state solution that is unperturbed so many stability analysis tools can be deployed on base flow
 - **Instrumentation and Layout**
 - APL has not received further input re: the instrumentation layout since PDR, nor has an update been worked to version 06... stay tuned
 - **Medtherm order**
 - APL worked out detailed mix of Medtherm types, configurations, and lengths that will allow most flexibility in installation to the Flight Geometry
 - Metherm provided quote which will be sent to APL procurement by end of week.

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- Nominal Medtherm delivery time on quote is 20-24 weeks, Medtherm reported will be able to deliver some sensors within that timeframe in batches which should enable APL to proceed with installation within estimated schedule
 - Medtherm gauges price came in a bit lower than estimated, so a few extra spares will be ordered of each type which will enable a couple of trial installs with live sensors
 - Thermal/Structural Analyses
 - Held meeting at APL to plan schedule and critical path for final thermal and structural analyses
 - Updated mechanical concept expected to be completed within the next two weeks, at which point the CAD will be defeatured as necessary and passed to Dr. Brian Kemp for completion of a final structural grid.
 - In parallel, APL will await updated trajectory from DLR. At approximately 1.5-2 weeks before completion of the structural grid, APL will assess the impending delivery of the DLR trajectory and if unavailable will use the AFRL Esrange trajectory for the final thermal analysis.
 - Seeking to have structural analysis complete and briefed internally to team by mid-December ahead of scheduling of CDR (to ensure entry criteria for CDR met)

11/10/2018 through 11/16/2018

- Upcoming dates/milestones:
 - 11/20/18 - AFRL/RQ deadline for ordering Sensor Boards
 - 11/29/2018 - Delivery of subscale model to Purdue for nosetip joint testing
 - TBD Late January - Critical Design Review (CDR)
- Mechanical Design
 - Completed revision to gutter mechanical interface
 - Met with structural analyst to define CAD features needed for structural mesh
- Thermal/Structural Analyses
 - Completed baseline plan for analysis of structural safety factors
 - Existing MSLRAD thermal code will be run on a new thermal grid incorporating relevant structural features
 - Structural grid is currently under construction, following completion of the grid the thermal results can be obtained rather quickly allowing the structural analysis to proceed
 - It seems likely we will not have a DLR trajectory soon, so our plan is to complete the structural factor of safety analysis with the AFRL trajectory for Esrange
 - The joint step height predictions can be done later in a second round of analyses if we receive a new trajectory sufficiently ahead of CDR
- Secondary (Roughness) Experiment

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- APL working with Scott Berry to define experiment concepts including fabrication and schedule constraints
 - Extracted shuttle criteria for trip transition onset from all BOLT mean flows and provided data to Scott Berry
 - Gathered and summarized all existing BOLT wind tunnel data with respect to roughness experiments and provided to Scott Berry
 - Instrumentation and Layout
 - Medtherm order has been placed and should be finalized today by APL procurement
 - Expected delivery timeline April 2019, partial deliveries ahead of 1 April expected to allow us to maintain schedule
 - 115 x TCS-061-TT-0.80-24-11586
 - 53 x TCS-061-TT-1.20-24-10607
 - 115 x TCS-061-EE-1.00-24-10607
 - Still to update layout to v06, anticipated this will happen Thanksgiving week
 - Ground Testing
 - Greg McKiernan went back and measured the molds from our August 2018 entry which included greater characterization of the spatial variation of the step that we (unintendedly) tested in that entry that caused transition. Separately, the model has been inspected at the APL shop and we've machined several new tips to serve as fit checks. We needed to build a new "nominal" tip that is flush with the surface before we can proceed building the purposely designed steps.
 - Thanks to both data sources, it seems almost certain that the nosetip in August was misaligned in a nearly pure spanwise direction. Greg's measurements reported the misalignment was greatest nearer to the gutter. The nosetip piece has a central aligning feature and also a dowel pin, which ideally should have been matched with the aluminum half of the model. However, the nosetip was machined during its final pass with the dowel actually engaged with the PEEK half of the model. Over time and various installations, the relatively short dowel pin wore away at the PEEK material around the alignment hole and is no longer properly engaging, causing some ability to shift the nosetip left and right.
 - We also have characterized, as part of this process, some of the observed asymmetries to features on our subscale model. The outer mold line was finished in the same final cut with all pieces assembled to ensure the geometry shape was correct, but internal nosetip centering features had an offset of about 0.011" between the PEEK and aluminum halves of the model. This could have arisen from a number of machining tolerances, since BOLT has limited flat surfaces to mount during machining. A 0.011" offset could have been caused by only a 0.05 degree tilt in the mounting plate leveling at the base, for instance. The difference is small, but explains why it was hard for TAMU to match parts we sent to them a while ago.
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- APL machine shop has been working on manufacturing a new baseline nosetip for the subscale model that is nominally flush to the frustrum and engages with the dowel pin alignment feature on the aluminum side
 - We are proceeding with this set of heights (8 total) for the next nose tips, defined by the peak joint step at the swept leading edge:
 - FORWARD FACING: 0.003", 0.006", 0.010", 0.020"
 - REAR FACING: 0.003", 0.006", 0.010", 0.020"

11/10/2018 through 12/14/2018

- Upcoming dates/milestones:
 - mid-January 2018 - Langley Fairing Test
 - TBD - Critical Design Review (CDR)
- Fabrication
 - TZM nosetip fabrication to commence at APL
 - Due to delays with deciding joint thermocouple instrumentation plan, and some unresponsiveness from the company, we missed our window to build the TZM nosetip out of house at Midwest Tungsten which quoted a 6-week delivery
 - Instead, we will proceed building the TZM nosetip in the APL shop
 - Material has been ordered from Ed Fagan Inc in NJ, expected to arrive early January. ASTM B386 type 364 (chemistry only) spec. Purchased 3 pieces (2 spares) in case of machining problems.
 - APL shop estimates on receipt of material, they can start fabrication within 2 weeks and complete with 30 hours labor.
 - Based on schedule outlined at PDR for the Ultramet coating, we are running about 4 weeks behind.
- Instrumentation, Layout, Sensor Boards
 - Science Instrumentation Layout
 - Completed v06 science instrumentation update following internal review and distributed on 11/28
 - Held telecon on 12/3 with team to finalize locations and types. Most discussion was centered on
 - Joint Thermocouples
 - Held smaller telecon to review joint thermocouple layout on 11/29
 - Increased joint thermocouples by removing 4 Medtherms and 4 empty/unused PMBW channels on new board variant
 - Increase from 8 Type K's to 14 Type K's. 7 total pairs.
 - Accommodated Scott Berry's desired layout, plus one additional pair was which added to the symmetric leading edge on the primary experiment Quadrant B.
 - Decided sampling frequency of Kulites

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- Directed RQ to design boards such that 8 of the 32 Kulites will be sampled at 70 kHz and the remainder at 15 kHz
 - This requires all sensors on the same DSP to be sampled in High-Speed mode in lieu of Hi-Res mode, which reduces the signal to noise ratio from 110dB to 106 dB, which was examined relative to the ranges of all sensors and deemed acceptable / low-risk.
 - Analyzed location of leading edge Medtherms around azimuth of radius and provided slight updates to the location to match with the location of predicted maximum heat transfer rate.
 - Sensor Boards
 - RQ now has all information needed to complete sensor board design and procurement and is working to get the board changes into drawings and obtain quotes for procurement
 - Mechanical Design
 - Revised flight hardware design to incorporate edge fastening system to allow for greater access to and ease of edge instrumentation
 - Prepared simplified flight geometry layout to aero-thermal analysis team for gridding and analysis
 - Added v06 instrumentation layout and continuing to work on SCB board and ballast weight placement to minimize interference with instrumentation layout
 - Met with APL machine shop representatives for a kickoff fabrication meeting as the fabrication plan nears
 - Working to accommodate joint thermocouple layout access
 - APL is assembling and working a "punch list" on finalizing the mechanical design
 - Thermal/Structural Analyses
 - Structural grid creation took longer than expected but is now completed in FEMAP format
 - The structural grid is currently being converted into the format needed for the APL MSLRAD thermal tool. Several issues were identified in the conversion such as node projections and small gaps.
 - Due to holidays and personnel availability the thermal analysis is not anticipated to be complete until after the Christmas holiday, earliest by 4 January if no issues are encountered
 - Structural analysis will commence following completion of the new thermal model. Structural results not expected until mid- or late-January.
 - Ground Testing
 - Purdue testing of nosetip joint steps
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- Worked with shop to understand as-fabricated details of Subscale BOLT model to create designs for and fabricate an array of tip replacements to evaluate step heights. Model and tip replacements shipped to Purdue 27Nov
 - Worked with APL inspection shop to inspect Subscale BOLT model to understand better what will be needed which regards to inspection of the flight geometry once that fabrication starts
 - Brandon Chynoweth completed testing at Purdue on the model with various nosetip steps (forward and rear facing) 3-8 December 2018
 - Brandon took molds of all nosetips and will need to characterize the actual as-tested step created by the different tips to fully understand the results.
 - Some preliminary overall results have been communicated by Brandon, but full data analysis is still underway:
 - On the TSP side all rear-facing steps including the largest rear-facing step (nominally 0.020") remained laminar under quiet flow including at 4-deg AoA and 4-deg yaw. The 0.020" forward facing step was fully effective at the same condition
 - Asymmetric results were observed between the PEEK side and the TSP/aluminum side. Either the PEEK side steps were different, or the PEEK part itself could be asymmetric due to manufacturing difficulties or thermal deformation as the part heats and cools. We'll have to wait until Brandon analyzes the steps on the PEEK side to get more information
 - The largest rear-facing step DID cause transition downstream on the PEEK side, when at 4-deg AoA, but was laminar at 0-deg AoA
 - Transition onset under quiet flow appeared in a narrow region appearing to coincide with one of the streak structures
 - Langley Fairing Test
 - NASA has planned a ceramic model test to examine the effect of fairing on heating for the Flight Geometry and TSM
 - The fairing test is scheduled in mid-January
 - The model will be a single model with 4 quadrants incorporating different fairings:
 - 2 quadrants will be AFRL RQ Fairing B, the baseline fairing
 - 1 quadrant will be the shorter CoDR fairing
 - 1 quadrant will contain no fairing
 - APL has been working to provide NASA with feedback and CAD files to allow completion of model design
 - CFD and Stability

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- Identified load cases to provide pressure loads for structural analysis and launched CFD cases, which should complete by end of weekend 12/15. Used Woomera trajectory and all cases run at $\alpha=5$ degrees:
 - 12.3s: Max Q
 - 20.4s: Local peak Q and $\max \rho \cdot v^3$
 - 24.5s: mid ascent experiment ($Re_L=10e6$)
 - 30.5s: end ascent experiment ($Re_L=2.5e6$)
 - 483.8s: early descent experiment ($Re_L=5e6$)
 - 485.9s: mid descent experiment ($Re_L=10e6$)
 - 487.3s: late descent experiment ($Re_L=16e6$)
 - 488.0s: end of experiment ($Re_L=20e6$)
 - Fairing CFD completed by Nick Bisek
 - No separation observed on Flight Geometry for CoDR fairing at Mach 6 AoA 2 deg 117 kft
 - Vortex frequency on order ~ 1 kHz
 - Provided Purdue with CFD data for step height test entry, to extract Re_k and local edge conditions at transition locations. Provided 155psia condition data at $\alpha=0$ and $\alpha=4$.

12/15/2018 through 1/18/2019

- Upcoming dates/milestones:
 - TBD, would like to try for late February - Critical Design Review (CDR)
 - uncertain due to government shutdown - Langley Fairing Test
- HIGH LEVEL SUMMARY
 - Structural "quick look" analysis expected early next week (week of 1/21/19), following which a telecon will be scheduled to discuss whether the design stresses appear acceptable to proceed to CDR and proceed with isolator and frustum rough cuts
 - TZM nosetip fabrication will be completed by the end of January, Ultramet coating schedule/cost details are being iterated
 - Government shutdown affecting NASA Langley and details of secondary experiment. APL will need to handle some decisions until Scott Berry is available to review.
- Thermal/Structural Analyses
 - Thermal analysis on new structural grid has been completed for Woomera trajectory
 - CFD-based tripping, +25% heat transfer coefficient margin is baseline case and is being used for the structural safety factor analysis
 - Cases with perfect conduction between parts and adiabatic ties between parts have also been conducted
 - Structural quick look analysis expected early week of 1/21 for key points along the Woomera trajectory.

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- These quick look analyses will be used to determine if we should proceed to CDR.
 - Following completion of the quick look structural analysis, a telecon with the internal team will be held to discuss the results
 - Final stress analysis to be completed with existing Woomera trajectory
 - Final step height analysis bounded by also a scaled Erange trajectory of some sort (exact process needs to be determined).
 - Trajectory
 - Received initial DLR 3DOF trajectory for Erange (v1.1).
 - The new DLR trajectory is consistent with the old Erange trajectory and the old Woomera trajectory. Overall integrated thermal load is within 1-2% lower compared to the old Erange trajectory and about 6% lower than the Woomera trajectory used for design loads)
 - There are open questions re: ballast needed due to less than predicted static margin (0.65 vs 0.72 calibers in pitch plane). RQ and APL to hold call 1/18 to discuss ballast requirements in Flight Geometry which are needing to be finalized.
 - Mechanical Design
 - The mechanical design is matured and drawings and fixturing part designs are being created for fabrication
 - Detailed drawings of fixturing hardware in progress
 - Design in progress for handling plates to protect leading edges during instrumentation
 - RADAX check fit hardware being designed and will be built and provided to RQ to check fit of TSM against Flight Geometry.
 - Continuing to check and finalize details like instrumentation mounting features and hole size tolerances. RQ and Sandia providing insight. Katya Casper at Sandia is doing experiments on Kulite hole tolerances and mounting material and sharing insights for BOLT flight.
 - Fabrication
 - Received TZM material from Ed Fagan Inc. in early January
 - TZM nosetip fabrication is underway at APL and expected to be completed by late January
 - After the TZM tip is completed the APL shop may begin fabricating items needed for isolator and frustum (fixturing hardware, radax joint check pieces, handling plates, etc)
 - Ultramet Iridium Coating
 - APL and Ultramet are currently in discussions about details of the Iridium coating
 - Ultramet is holding internal discussions about the job of coating the TZM tip due to larger scale than previous HIFiRE nosetips.
 - Ultramet and APL due to discuss in detail early week of 1/21/19.

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- Hope is that Ultramet will not charge engineering development fee for hardware they claim may be needed for the coating
 - Instrumentation Procurement - Reaching out to vendors for updates on orders in progress:
 - Medtherm - has not yet responded
 - Kulite - confirmed two orders expected 1/25/19 and 2/25/19... verified 1/15/19 these are on schedule
 - Vatell - Can't order before 1/23/18 due to plant shutdown. After 1/23/19 will obtain new quote. Lead time was running ~4 weeks so there is time with this order. May hold until later to manage reserve Year 2 funding ahead of next funding increment.
 - PCB - scheduled telecon to discuss timeline and integration details with GHI
 - Instrumentation, Layout, Sensor Boards
 - APL designed a split of primary vs. secondary board placement on the Flight Geometry that will allow for no wires crossing between subassemblies. The design requires 8 of the 24 secondary experiment Medtherms to be placed on the primary surface. However, Scott Berry had expressed interest in using some of the secondary experiment instrumentation on the primary experiment surface.
 - Dave Adamczak reworked sensor mapping and incorporated into a Revision 1.6 master spreadsheet that maps the sensor boards to DSP's and telemetry streams. Rev. 1.6 includes a slightly better split of the Vatell gauges between the three TM streams.
 - Sensor board procurement in process and Dave expects many boards to be in by the end of January.
 - Mapping of individual sensors to each board is in progress but is delayed by many other pressing items.
 - Internal volume constraints for the wiring are likely to limit too much "crisscrossing" of wires and a "closest approach" method to the boards is likely to be necessary.
 - The exception to "criss-crossing" wires is the low-pressure Kulite sensors, which are being designed with redundant sensor locations split amongst DSP and TM streams so that a DSP failure or TM stream dropout risks to the critical reconstruction of vehicle attitude will be minimized
 - The primary balance constraints are thus to mix boards leading to the same DSP's and same TM streams from being concentrated in any one portion of the Flight Geometry.
 - Secondary Experiment
 - Scott Berry has been offline since 12/24/18 due to the government shutdown affecting NASA Langley and has been unable to contribute to the secondary experiment design during this time.
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- Prior to Christmas, a streamline tracing approach was identified for determining probably locations of transition onset for the upstream and downstream joints.
 - APL plans to proceed with a baseline secondary experiment layout based on previous communications with Scott Berry in the hopes that when the shutdown ends, Scott won't have to start from scratch.
 - Proposed secondary experiment rear-facing step will be developed concurrently with the incoming step height predictions from the structural analysis, APL will be estimating probable ranges of differential expansion for several points of flight to present at CDR. We need to know the step height for the secondary experiment ASAP to enable fabrication of the isolator!
 - Ground Testing
 - NASA Langley fairing test presumably delayed due to government shutdown, status unknown until the government reopens
 - APL ground testing efforts are finished, documentation to be completed post-CDR
 - Model to be transferred to Texas A&M for testing in Spring 2019
 - Purdue also has plans to test with the model, modified, or a new model, in Fall 2019 or later.
 - Team was meeting held at AIAA SciTech 2019 with purposes:
 - Coordinate ongoing group efforts now that APL is finished with ground testing campaign and CFD/stability analyses (except for those planned in future to support flight test data analysis)
 - Discussed university group plans for follow-on research for BOLT
 - Decided TAMU will hold BOLT subscale model long-term as the model is a deliverable to AFOSR and APL is finished with it

1/19/2019 through 1/25/2019

- Upcoming dates/milestones:
 - TBD, would like to try for late February - Critical Design Review (CDR)
 - uncertain due to government shutdown - Langley Fairing Test
- Fabrication
 - Trying to get parts in current state into APL shop to get them working on fixtures and roughing. APL's space department reportedly will put in months work of work soon, and we're trying to secure a slot in the queue before that happens.
 - TZM nosetips have been completed and are in our possession as of 1/24/19
 - Three total tips were made, but one part was gouged due to programming error (to be used for trial runs at Ultramet)
 - Have two "good" parts, one to serve as spare in case of issues with Iridium coating
- DLR Trajectory

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- DLR has requested we increase our static margin in the pitch plane to 1.0 cal at max. dynamic pressure.
 - DLR to re-run trajectory with latest ballast information to see mass impacts on Mach/Re and stability
 - Mechanical Design
 - Reworked ballast from 14kg at 0.386m to 32.2kg at 0.345m. Planning this ballast as baseline and removal of material will be possible later as needed.
 - Working variety of detailing on drawings and parts to get them in good shape for fabrication
 - Thermal Analysis
 - Had discussed scaling CFD-based points to Esrange (Tr, HTC).
 - Could use DLR v1.1 trajectory. Altitude provided in kilometers and planning to use standard atmosphere (1976) model for freestream conditions.
 - Holding meeting with thermal analyst to determine cost and scope of scaling. We need to consider budget impacts on remaining thermal and structural work!
 - Structural Analysis
 - Held internal meeting to review status of structural analysis, and quick look briefing will not be available this week as originally anticipated
 - Thus far, no show-stoppers seen in structural connections between parts (TSM, Stainless, Aluminum)
 - We are waiting on a better modeling of the RADAX joint between the Flight Geometry and the TSM with thermal + aerodynamic loads
 - We are gridding a portion of the TSM in order to provide more accurate structural constraining at the bolt connections
 - The current model of just the BOLT side of the RADAX joint does not allow us to model a physical connection. Constraining arbitrarily results in non-physical stresses.
 - The Flight Geometry/TSM joint temperatures are cool and we don't expect issues, but we want to be sure
 - We are re-checking all the analysis from last summer to verify there is no surface structural yielding during ascent (in progress)
 - Performed linear analysis only at this time. As predicted last summer there is yielding during the last few seconds of flight in a few regions right on the surface (non-structural regions) and we are working to quantify and report those. Deformations could be predicted with nonlinear plastic deformation analysis and would affect step height predictions.
 - Ultramet Iridium Coating
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- Wolf and Wheaton held telecon with Ultramet (Andrew Duffy and Victor Arrieta) on 1/22/19 to discuss process and risk with Ultramet coating. Discussed processes and risks.
 - Ultramet provided quote of \$59K for BOLT nosetip
 - \$19K higher than previous ROM estimate when we quoted two parts
 - Price of Iridium has risen significantly in past year (up 40%)
 - BOLT nosetip scale is larger than previous parts coating for HIFiRE flights due to the geometry, so Ultramet had been holding internal meetings to assess processes and risk created by the scale-up
 - Ultramet has determined they DO have adequate size CVD chamber to accommodate the BOLT nosetip
 - Ultramet will need to develop new hardware to fixture the BOLT nosetip part into their CVD chamber, and motor/gearing hardware to rotate the part during application
 - Ultramet requested a new bored 3/16" hole for an in-depth thermocouple deeper into the TZM tip part for placement of a thermocouple to measure bulk temperature during application (part is heated to temperature). Tom to inquire with APL shop if hole can be added.
 - Ultramet will plan risk-reduction trial run(s). A spare/gouged TZM tip part can be provided by APL for these risk-reduction trials. Price would include practice run with the spare part up to ~50% coating application.
 - Ultramet concerned if back face corner is left perfectly sharp there could be risk of thermal stress and propagating cracking, suggested slight sanding of the back face corner could alleviate the risk somewhat (said previous HIFiRE hardware may have determined this was acceptable)
 - Part to be fixtured upside down resulting in thickest coating at the leading edge as desired
 - Ultramet requested final finish from APL machined part NOT be highly polished to specification, as the polishing will be done by Ultramet on the final coating to achieve the specified surface finish 8 microinches rms.
 - Final polishing of BOLT tip will be more challenging than conical tips and Ultramet is still thinking about how to do it. Previous polishing was a spindle-based method for the conical geometries.
 - Schedule (6-8 weeks if all goes well) - 3-4 weeks for facility development and fixturing part fabrication, additional 3-4 weeks for trial runs(s) and risk-reduction before completing coating. Ultramet is working to do some of this ahead of the purchase order.
 - Instrumentation Procurement - Reaching out to vendors for updates on orders in progress:
 - (NEW) Medtherm - spoke 1/21 with Dale Watring. Final delivery still on target for 1 May 2019. Reiterated request for partial deliveries. Medtherm to first deliver 3-4 sensors of each type ordered by APL for measuring tolerances and potential trial installations.
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- Kulite - confirmed two orders expected 1/25/19 and 2/25/19... verified 1/15/19 these are on schedule
 - Vatell - Can't order before 1/23/18 due to plant shutdown. After 1/23/19 will obtain new quote. Lead time was running ~4 weeks so there is time with this order. May hold until later to manage reserve Year 2 funding ahead of next funding increment.
 - (NEW) PCB - discussed timeline and integration details with GHI
 - Instrumentation Layout
 - Developed next iteration of secondary experiment layout in NASA's absence due to Government shutdown. Slides posted at <https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Flight%20Test/Secondary%20Experiment/2019-01-23-secondary-exp-layout-v02.pptx>
 - PMBW (high-frequency Kulites) Selected 70kHz Kulite locations. Sought input from students doing analyses.
 - PLBW, PMBW, and Vatell board mappings completed. Medtherms next.

1/26/2019 through 2/8/2019

- Upcoming dates/milestones:
 - 18 February 2019 - Fabrication to begin on Aluminum aft body parts
 - 27 February 2019 - Critical Design Review (CDR)
 - TBD - Langley Fairing Test
- Fabrication
 - Aluminum 6061 surfaces and gutters released to APL shop for material ordering and fixturing hardware. Parts not yet authorized for fabrication. Aiming for final parts release with updated CAD and drawings by 11 February 2019.
 - RADAX check fit hardware released to APL shop for fabrication.
 - Sent to RQ and GHI for one final check on RADAX joint
 - Parts to be built shortly
 - Meeting held 2/5/19 with APL shop supervisors and machinists to talk schedule and details of fabrication.
 - To meet April 1st deadline for completing aluminum frustrum components the following needs to be decided ahead of CDR (to enable completed CAD and drawings no later than 2/14):
 - Primary surface step height aim points
 - Secondary experiment layout
 - Secondary experiment step height aim points
 - Shop estimates 3 weeks per aluminum surface. We are aiming to have the primary experiment surface done first, so instrumentation can be added.
 - Discussion on how the parts will be held and what will all be done in the first "operation."

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- The interior will be excavated first with milling, and counterbore features added, all in the first operation. This is so that all of these features can be located accurately.
 - Discussion on which instrumentation holes must be added from the interior versus those that will be added from the exterior
 - Vateils and PCB's are counterbore features that need to be added from the interior, prior to contouring the outer surface. Some minimal deburring will be necessary for these! Shop will use best effort to maintain a sharp break on the exterior surface. These instruments were already placed downstream due to their larger diameter so some small amount of deburring is acceptable.
 - Medtherms will most likely all be added from the exterior contoured surface so that no deburring will be needed. However, counterbored access holes in and around the leading edges will need to be done before in the first operation.
 - Discussion on how to apply thermocouples into TZM tip joints with minimal risk to the surface finish. The TC's are applied with a peening hammer and we may have to build an inverse nosetip out of plastic/felt or silicone to protect the finish during hammering.
 - Discussion on isolator and sizing the steps. The shop feels that the isolator part is relatively easy to build such that we should be able to build different versions until we get the steps very close to where we want them, much like we did with the Purdue model nosetips.
 - Aerodynamic fairing concept is being run by machine shop, potentially looking at additive metal manufacturing for these parts.
 - DLR Trajectory
 - Received version 1.2 DLR trajectory which included +32.4 kg mass ballast
 - Static margin was very good > 1.2 cal in pitch plane worst case
 - Mach number dropped by 0.2 on ascent but still above 5.0 for most of ascent experiment window
 - Descent Mach number dropped from 7.7 to 7.2 compared with v1.1
 - DLR ran v1.3 with +22.4 kg ballast
 - To see how much Mach number increases
 - The -10kg ballast reduction compared to v1.2 increased ascent Mach number by about 0.08
 - Increased descent Mach number to 7.4 (about the same as Woomera trajectory)
 - This trajectory selected for final thermal analyses @ APL
 - Mechanical Design

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- Aerodynamic margins very good and controllable with ballast in Flight Geometry, as such no reason to shorten the aerodynamic fairing. We are proceeding with detailed design using RQ Fairing B design.
 - Created preliminary fairing design that could be additively manufactured with metal.
 - Awaiting PCB enclosure design modification from GHI expected in a couple weeks
 - Chasing down all sorts of final details! Trying to get parts in fabrication soon.
 - Thermal Analysis
 - Completed definitions of scaling factors to scale Woomera CFD heating and recovery temperatures to new Esrange DLR v1.3 trajectory.
 - CFD cases shifted to match same altitude at new time in Esrange trajectory (ascent CFD points shifted earlier an average of 1-2 seconds, descent times shifted forward approximately 40 seconds)
 - Assumption for tripped cases is that same tripping locations used for same altitude
 - Recovery temperature scaled with factor $(1+r*0.2*M^2)$
 - Cold wall heat flux scaled by factor $(\rho*u^3) \sim u^3$ since the altitude was matched in general
 - Both scaling factors were spot checked against separate CFD solutions at the same altitude with arbitrarily increased freestream velocity +10% and found to be adequate, at least for laminar heating regions
 - Thermal analyst returned from leave 4 February at which point the thermal model re-run was attempted with the DLR v1.3 trajectory
 - We are experiencing issues with the scaling code and the new cases that use CFD solutions are not converging. Development team for the thermal code is investigating.
 - The issues is occurring when the thermal simulation switches from correlation-based heating to CFD-based heating around ~11seconds after launch. There is likely a local discontinuity in heat flux that is too large somewhere on the body that is causing convergence issues.
 - We ran one additional CFD point at $t=10s$ that may help facilitate the handoff between correlation and CFD heating solutions.
 - We DO have solely correlation-based heating runs for both Woomera and DLR v1.3 that we have used to estimate the trajectory effects on bulk temperatures, and make the argument that we do not need to repeat structural analysis on the Esrange trajectory (design closes for more stressing Woomera anyways, step height estimates not likely to change by more that ~6-7% and will be small on the order of 0.0005" or less, below all other uncertainties).
 - The correlation based model plots were made showing that bulk temperatures are roughly 5% lower for Esrange, vs. Woomera

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- Structural Analysis
 - Completed featuring of RADAX joint between BOLT geometry and TSM for more accurate stress concentrations.
 - Received feedback from AFRL/RQ on initial structural results, extra plots requested, etc.
 - Working on completing final structural briefing and step height raw data
 - Joint Cold-Wall Step Sizing
 - Generated scaling plots to flight conditions for 4 different roughness correlations based on 0-deg Purdue data from December (0.006" forward facing step and 0.020" rear facing step remained laminar). Correlations chosen all have considerable uncertainties but the data are easy to pull from CFD:
 - Re_k (based on local height conditions)
 - $Re_{k,edge}$ (based on BL edge conditions)
 - k/δ (step height relative to BL thickness)
 - $Re_{\theta}/M_e k/\delta$ (shuttle correlation)
 - ALL of these correlations are being evaluated at conservative assumptions (cold leading edge wall temperature of 400K from CFD, maximum roughness height expected around the azimuth, minimum boundary layer thickness locations)
 - Awaiting final differential thermal expansion numbers to add proposed set point data to these plots for CDR
 - Plot to be shown ahead of CDR along with proposed step heights set point
 - Ultramet Iridium Coating
 - Spare/damaged nosetip part shipped to Ultramet 28 January.
 - To be used for trial coating and risk reduction efforts.
 - Funny story (now, because it wasn't funny at the time) but FedEx delivered this to the wrong address and a Good Samaritan named "Tony" was able to contact Ultramet and have them pick up the package!
 - APL is processing the PO to Ultramet.
 - We received caveat language in the PO that we had to authorize from Ultramet:
 - "The drawing has a call out of 50-100 microns thick and a surface finish of 8 microinches. Ultramet will make its best efforts to achieve these results; however, we cannot guarantee/warranty that the coating will be in compliance. We have scheduled an initial trial run on a scrap part to assist in our validation of the coating. After the trial, a discussion will be had with JHUAPL engineering/program management to discuss the results and go forward plan on coating the deliverable."
 - Instrumentation Layout
 - Created scripts to plot mapping of sensors to boards/telemetry in Tecplot for CDR
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- Recorded (x,y,z) sensor mappings from temporary planning apparatus (cork board) to spreadsheet coordinates
 - Completed mapping of primary surface instrumentation to boards!
 - The mapping was done to balance complexity of wiring and assembly with redundancy from two unlikely events:
 - Failure of a single DSP
 - Temporary or permanent loss of telemetry from one of three streams
 - By undergoing this process we also found 3 extra holes in the gutter that are now corrected to match the final layout v06
 - We also found a single duplicate/double-counted instrumentation location and were able to relocate that Medtherm to the primary surface on Quadrant B.
 - We now also have nominal X/Y/Z locations mapped to each individual channel of each board which will facilitate generating drawings and instructions for the technician who will be running our wires in a few months
 - Secondary Experiment
 - Re-worked sensor mappings to move one board to the secondary subassembly, allowing a "clean split" in terms of wiring.
 - Discussed potential of aiming for two rear-facing steps of different heights
 - Brad Wheaton and Scotty Berry holding numerous conversations throughout this week on options for steps and layout of secondary side. Options to be presented to larger group on Friday 2/8 telecon and hopefully finalized early week of 2/11 to be incorporated into the CAD and final drawings for the shop.
 - Instrumentation Procurement - Reaching out to vendors for updates on orders in progress:
 - (NEW) Medtherm - Medtherm promised initial delivery but has still not yet committed to firm date for first partial delivery. They last claimed final delivery was on schedule for 5/1/19. We are consistently following up with them!
 - (NEW) Kulite - Received all items from first order. Second order of +16 -5A sensor expected 2/25/19... verified 1/15/19 these are on schedule
 - Vatell - Re-sent request for quote. Have not received.
 - PCB - discussed timeline and integration details with GHI

2/9/2019 through 2/27/2019

- Upcoming dates/milestones:
 - 18 February 2019 - Fabrication to begin on Aluminum aft body parts
 - 27 February 2019 - Critical Design Review (CDR)
- Structural Analysis
 - Received final joint differential expansion numbers and used differential thermal expansion predictions to set cold wall joint step aim points. Results and aim points were briefed to internal team via telecon on 2/15/19, along with additional e-mail discussion

about assumptions. The telecon slides are stored at <https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2019-02-15-BOLT-joint-step-sizing-final.pptx?Web=1>

- Structural analysis of bolt loads led to an increase in the size of the frustum to isolator bolts. These bolts were originally #10 UNF and were increased to ¼" UNF bolts to add additional margin to the axial/tension loading on the bolts under combined aerodynamic and thermal loads at the end of flight. The larger bolt size also has a benefit of increased contact area with the aluminum to reduce pull-through stress.
- Mechanical Design
 - Much effort leading into CDR to complete the final CAD and drawings of the aluminum main surface part to enable fabrication to begin.
 - Hole size tolerance discussions on the Kulites were again held with Sandia based on their trial run installations of Kulites.
 - Completed addition of secondary experiment step into CAD model
- Thermal Analysis of Fairing and TSM
 - Ahead of CDR, APL worked on completing a quick look thermal analysis of the aerodynamic fairing mechanical concept, and also included the TSM in the thermal analysis to provide additional comparisons to RQ heating predictions
 - Existing CFD cases of the Flight Geometry forebody were leveraged. Flow from the downstream end of the Flight Geometry was used as an inflow profile boundary condition to a new grid including the fairing and the TSM. The fairing/TSM grid was generated with Pointwise T-Rex meshing methods and included hex-dominated boundary layer cells with wall spacing $y^+ \sim 0.2-0.5$.
 - 30 new CFD cases were run to simulate the flow field around the fairing and TSM. The cases were run fully turbulent with the SA model, and both cold-wall and adiabatic wall BC's were used at each trajectory point. From these cases a heat transfer coefficient and recovery temperature distribution were calculated, and a 20% extra safety margin was added to the heat transfer coefficient.
 - A new solid grid was completed and the HTC and recovery temperature was mapped onto this grid for a new transient thermal simulation. The thermal response was completed in CFD++. The results are still under analysis but were shared with AFRL/RQ.
- Secondary Experiment
 - Team held detailed discussion on 2/8/19 on the secondary experiment tradeoffs between single and dual step configurations, slides 3-7 of <https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2019-02-08-BOLT-update.pptx?Web=1>
 - Debate was primarily centered on two experiment options:

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- Single rear-facing step repeated nominally on both leading edges of the secondary side
 - Two different height rear-facing steps on each of the two leading edges on the secondary side
 - Single-step configuration
 - Advantage was noted that repeatability of results could be assessed if you had two nominally similar steps and were able to obtain measurements that agreed with each other during flight
 - The other advantage was that potentially additional spatial resolution could be obtained, if desired, because of the notional symmetry of the experiment. One side could focus on an increased number of sensors for spatial resolution of the step wake, while the other side could have fewer sensors whose goals were to assess symmetry.
 - Disadvantages noted that only one nominal step height would be selected, and thus only one transition onset data point would be observed through flight
 - Dual-step configuration
 - Advantage was noted in that two transition onset data points could be observed from each of the two different step heights. The step height parameter could then be tested in flight, as opposed to the single-step configuration where that parameter is fixed.
 - It was noted that this configuration necessarily would require a largely symmetric sensor layout.
 - Disadvantage to this was that given the uncertainty in the growth of the joint in flight, and also the unknown level of precise control of the joint step, that it would be difficult to interpret results definitively without some sort of confidence gained from having nominal symmetry in the experiment and measurements.
 - Discussion was held with all on the line, but no single consensus between the single-step and dual-step options could be obtained during the telecon.
 - Decision was left to Scott and Brad.
 - Completed secondary experiment layout after post-call long discussion with Scott Berry on 2/8/19. The final layout can be found here:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/Flight-Planning-Telecons/2019-02-08-secondary-exp-layout-v05-postcallchanges.pptx?Web=1>
 - Selected single-step configuration for flight. Both Brad and Scott saw both the pros and cons of the single and dual step configuration, but in the end decided

that a nearly symmetric sensor layout would be desired for either option, and that it would be beneficial to observe repeatability in the results.

- Brad and Scott moved three Medtherms, which are reflected in the powerpoint slides above.
 - Brad discovered that the near-joint Medtherms would be easier to install if they were on the leading edge itself, which is actually where Scott preferred them. It is still a slightly more challenging installation but acceptable level of effort if it is limited to two leading edge sensors on the secondary side.
 - Scott requested one Medtherm be moved to centerline near the back of the Flight Geometry acreage.
- Having finalized the instrumentation layout and concept for the experiment (single-step, rear-facing), but lacking final thermal expansion growth predictions from the smooth side as of 2/8/14, Brad and Scott agreed to reconvene on 2/14/19 and set the final secondary experiment step and contouring. Brad provided Scott with correlation slides and ROM estimate of cold-wall step size on the primary side.
- Ultramet Iridium Coating
 - Ultramet planned to complete their trial coating run on the spare test tip by end of week 2/28/2019
 - APL shipped the primary and spare nose tips to Ultramet on 2/26/2019, and the pieces were confirmed received.
- Instrumentation Procurement
 - Vatel production issues are being monitored. One Vatel gauge was available and ordered.

2/27/2019 through 3/7/2019

- Upcoming dates/milestones:
 - 11 April 2019 – Expected completion of primary experiment surface with all instrument holes, ready for instrumentation
- Critical Design Review (CDR) held 2/27/2019 at JHU/APL
 - Final slides posted here:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/2019-02-27-Critical-Design-Review/BOLT-CDR-Slides-ALL.zip>
 - Meeting discussion notes here:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/2019-02-27-Critical-Design-Review/BOLT%20Critical%20Design%20Meeting%20Notes.pdf?Web=1>

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- Attendance list here:
<https://partners.jhuapl.edu/sites/AFOSRBOLT/Shared%20Documents/Meetings%20and%20Reviews/2019-02-27-Critical-Design-Review/BOLT%20Critical%20Design%20Review%20Sign-In%20Sheet.pdf?Web=1>
 - CDR Action Items and Responses:
 - Aaron Dufrene (CUBRC) had concerns about TZM thread residual stresses and potential effect on material from Ultramet coating application
 - Verified with APL machine shop that the TZM nosetip bolt holes were not tapped, but rather a thread mill was used. The shop was aware of tapping not producing quality threads on TZM.
 - Fine thread was used, but the bolts for the tip are 5/16" not 1/4" as originally thought, but both bolt sizes are larger than previous HF5b bolts.
 - Ultramet is only heating the part to 500 degC for the coating application, followed by a 700 degC heat treatment of the part that relieves internal stresses in the coating. Ultramet reports this heat treatment is well below the recrystallization temperature of TZM (~1400 degC) so they are not concerned with changing any material properties.
 - Exchanged several e-mails with Aaron to relay information
 - Joe Norris asked APL to obtain ROM cost for testing (thermal, vacuum, vibration) at JHU/APL to alleviate schedule risk of RQ facilities not under direct control.
 - Verified that JHU/APL has the facilities of proper size to complete the thermal, vacuum, and vibration testing. RQ provided CAD of the PSM shell to add to the APL CAD files to verify the dimensions of the test hardware.
 - These facilities are available and open starting at the end of April 2019, and generally available with 2-3 month advance notice.
 - The tests could likely be completed in well under a month, which could reduce schedule risk considerably if they would be used.
 - ROM cost obtained and delivered for future discussion
 - Clarification on surface finish requirements of TZM tip
 - APL has requested 8 microinches RMS. Ultramet has only promised "best effort" on finish because the 3D part will be more difficult to polish than earlier axisymmetric nosetips.
 - Clarification on tolerance for joint steps: does the 0.008" step include the 0.002" margin
 - Yes, the cold wall aim points include the nominal 0.002" margin. The differential thermal expansion prediction was ~0.001" for the upstream joint and ~0.006" for the downstream joint.
 - Action to get nail polish holding procedure from T9 when installing Kulites, to keep them straight.
 - APL to document and provide critical path to flight
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- Held Post-CDR Meeting with AFRL/RQ at JHU/APL on 2/28/2019
 - Attendees: Wheaton, Wolf, Dolvin, Adamczak, Tancred, Borg, Bisek
 - Discussion topics:
 - TSM threads
 - Export planning
 - Fairing and TSM heating... review of APL quick look data, discussion of path forward. Jim Tancred and Nick Bisek were provided with APL heat transfer coefficient data. Resulted in some updates to APL analysis.
 - Critical path
 - Environment testing requirements and schedule, APL testing ROM
 - Tour of manufacturing facilities
 - Further verification and discussion of Medtherm hole tolerances and installation procedures
 - Mechanical Design
 - Working to complete final detailed drawings on all features of the primary and secondary surface drawings for the machinists.
 - After CDR there was further discussion with Dave Adamczak suggesting that the tolerances for the reamed Medtherms holes were likely slightly too tight. Too tight a hole can cause the Loctite to seize up during installation. Adjustments to the tolerances were made to better match tolerances provided by RQ.
 - Performing additional checks of all sensor holes... CAD versus drawings versus final layout. Discovered missing PCB in the CDR CAD... only seven were shown instead of eight. This is being corrected for the final surface fabrication.
 - Reviewing final sensor board mounting locations to ensure maximized room for wiring.
 - Fabrication
 - Began fabrication of aluminum main surface piece (primary experiment surface) on 2/26/19.
 - Unfortunately, two days into fabrication it was realized that the reduced-feature “no holes” CAD file that the shop requested did not include the alignment tabs on the front of the aluminum surface, for the isolator joint.
 - Because the piece is being cut much faster than anticipated, it was decided to continue machining the first piece as a workable spare part even without the alignment tabs. This will serve as a risk-reduction engineering development model that will allow the machinists to refine the programming for each cutting step, and “practice” challenging tool paths or holes.
 - A limited number of the challenging instrumentation holes will also be added to permit trial installations on this part.

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- Following completion of the EDM, an identical surface will be machined as the new primary flight part. EDM completion expected 8 March 2019.
 - An extra billet of spare aluminum was ordered to offset the loss of the first spare billet.
 - The final primary experiment surface roughing is expected to begin 11 March 2019, followed by the secondary experiment surface.
 - The anticipated completion date of the primary experiment surface with all hole features, ready for instrumentation, is 11 April 2019.
 - Ultramet Iridium Coating
 - Ultramet encountered a problem with the test piece that delayed the trial run. A bolt became fused with the threads during a heating trial and the head snapped off. They are developing and testing alternate methods to hold the TZM part.
 - APL held a telecon with Ultramet on 3/5/2019 to review the issue in detail, how/why it occurred, and review Ultramet's path forward.
 - On previous nosetips for HIFiRE, the nosetips were set on a holder vertically and the CVD gas flowed from top to bottom. The BOLT tip is being held upside down, with gas flowing from bottom to top. Ultramet decided to do the application this way as it offered benefits for their motor to move the part, and also keeps particulates from settling back onto the nosetip region. They said it is common for them to apply coatings upside down depending on the part.
 - Because the part is hanging upside down, they had to mount it and hold it, and were using existing TZM threads. First they attempted stainless steel bolts and then molybdenum bolts. Both got stuck in the test piece threads during the trial heating process. When they tried to remove the molybdenum bolt, the bolt head sheared off. Adding to the challenge is they were trying not to use lubrication in the threads, because the lubricant could contaminate the CVD chamber. So the threads were dry.
 - Their solution path forward was to clean up the threads on the test nosetip and used each of the two bolt locations to test two candidate bolts for the final nosetip application process.
 - One bolt will be a graphite bolt
 - The other bolt will be stainless, but with a graphite lubricant.
 - They will heat up the part and then test removal of each of the bolts.
 - With the final bolt material APL verified that they do not plan any need to rework any of the threads in the final pieces, provided that the bolts being tested will be removed easily.
 - Verified that the application temperature of the coating is 500 degC
 - They do post heat treatment of the coating up to 700 degC, but this is for the coating and they reported this is well below the recrystallization temperature of TZM (which they said was near 1400 degC).
 - Thermal Analysis of Fairing and TSM
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- Re-ran fairing and TSM CFD cases after discovering a mistake in the adiabatic wall cases.
 - Recalculated the heat transfer coefficient and recovery temperature for the corrected CFD cases
 - Re-ran the transient thermal analysis of the fairing and TSM to compute temperature rise during ascent (for now using an initial temperature of 400K). The temperatures in the fairing are very low at the end of flight. Shared TSM temperatures with AFRL/RQ and thus far it seems that no cork TPS will be required on the TSM.
 - APL ran a new ascent transient thermal analysis to compute the temperatures at the end of ascent. A thermal soak solution is now running to allow conduction and evening out of the temperatures throughout the fairing and TSM. The soak case will be run for ~60 seconds or so, or until the temperatures are fairly evenly distributed. Following completion of the thermal soak run, the descent simulation will be re-run with a more accurate initial temperature to compute the final temperatures expected at the end of flight.
 - Ground Testing
 - APL provided NASA Langley with suggested analyses for the fairing and TSM aeroheating test data. These included providing heat flux in a unit that can be compared to CFD cases, and to look at averaging the heating along spanwise slices to see if the roll-integrated heating is less than the 0-deg heating. Provided request for heating data to be shared with Nick Bisek at AFRL/RQ.

3/8/2019 through 3/14/2019

- Upcoming dates/milestones:
 - 1 April 2019 – Flight Research Vehicle CDR
 - 11 April 2019 – Expected completion of primary experiment surface with all instrument holes, ready for instrumentation
- Fabrication
 - Primary experiment surface internal contour and internal features are complete as of 3/12/2019
 - Secondary surface internal contour and internal features are nearly completed
 - Next week, it is likely that the outer contour cutting will begin for the Engineering Development Model (EDM) piece, as well as initial trial cuts of outer instrumentation holes on the EDM piece.
 - They will also use the EDM piece at some point for a practice cut of the additional material removal planned for the secondary experiment rear-facing joint step.
- Mechanical Design
 - Completed drawings with hole tolerances for both primary and secondary experiment surfaces

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- Continuing to review CAD and part files on delivery to the machinists to ensure all part features are captured correctly
 - Several minor modifications since CDR to primary and secondary experiment surface part design. All modifications are captured and archived in CAD files.
 - Added missing PCB location (as noted in last week's update, one was missing in CDR CAD)
 - Decreased depth of counterbore hole by 1/16" for bolts that connect the aluminum frustum to the isolator, and increased counterbore hole diameter from 0.406" to 0.438". Adds additional thickness to bearing depth (clearance from Medtherm access hole in vicinity) for the bolts to resist pull through forces. Larger diameter hole enables use of 7/16" washers to increase bearing area of bolt to resist pull through forces, and use of washers will decrease wear and tear or gouging chances on aluminum. Contact area increased ~20%. The pullout force was acceptable in the previous design, but this easy change adds additional margin.
 - Slightly adjusted leading edge Medtherm internal counterbored access hole angles to increase clearance from other internal holes and for easier machining access on secondary surface
 - Simplified access features for outboard Medtherms on secondary surface when able, to reduce challenging counterbored angled access holes.
 - Added mirrored mounting features to secondary surface for GHI PCB box for flexibility in case the box needs to be moved unexpectedly to the opposite side after wiring is added.
 - Removed localized knife edge condition created by tool access holes on gutter surfaces
 - Shipped RADAX joint test fixture to AFRL/RQ on 3/12/2019
 - Initial order of Medtherms received (qty 6...166 to go!)
 - These are measuring on the very low end of Medtherm's quoted tolerance of 0.0607 +0.0008/-0.0002. The hand measurements via digital calipers were ~0.0605 on the low end, confirmed by machinists with micrometer. Measured closer to 0.0610 in some places. Machinist said the diameter does appear to be within Medtherm's quoted tolerances, but nearer to the lower end, on the current batch of sensors that APL has.
 - The current hole tolerances of 0.0620 +.0010/-0.0005 (0.0615 to 0.0630) would result in holes slightly larger than the Medtherm quoted "0.0005 to 0.0015 inch larger than the outside diameter of the coaxial thermocouple" up to 0.0025 inches max, which is consistent with AFRL's previous range (0.0618 to 0.0626 in.). Per conversations with RQ it's better to have them loose than too tight,

because they can seize up during installation if too tight and then removal is nearly impossible in aluminum.

- Ultramet Iridium Coating
 - Ultramet successfully completed a trial run of Iridium coating on the spare nosetip test piece... “looks great” via Ultramet email 3/7/2019
 - Both new bolts tested (graphite and graphite-lubricated steel) came out of the part with no problems. They’ll use one of each on the final part (if graphite bolt fails, thought is that steel bolt will catch it).
 - The coating at the leading edge achieved the desired thickness 0.004” and “most of the surface has at least 0.002 in.” thickness
 - Ultramet is performing additional checks on the coating... dye penetrant, surface roughness, and residual stress analysis
 - APL received test inspection report on coating thickness and post-CVD surface roughness on 3/12/19 and followed with a telecon with Ultramet
 - Asked some additional inspection clarification questions and requested a few more measurements of coating thickness for the final nosetip (spanwise distribution along nosetip leading edge, additional characterization around swept leading edge)
 - The coating numbers and distributions looked very good from the inspection report. The coating is thickest at the nosetip, although APL had requested additional measurement locations for the final tip. The coating is thinnest in the recessed gutter centerline (~0.001”) but this was deemed acceptable for the noncritical portion of the geometry.
 - Surface RMS varied 35-50 microinch RMS following CVD application. Ultramet is now evaluating several polishing methods to apply to the test piece to achieve the target 8 microinch RMS finish.
 - Ultramet also tested “breaking” the rear edge on the test nosetip.
 - An unbroken or nominally sharp rear edge is desired to minimize any small gapping at the joint.
 - However, a sharp edge also created local stress risers which could cause risk of cracking the coating in that region.
 - Ultramet tested the “as received” rear edge with a measured radius of 0.002-0.003 and a “handworked/broken” rear edge with a radius of 0.005-0.007.
 - After coating, the coated part measured R 0.005” (unbroken edge) and R 0.010” (broken edge), since the coating added ~0.002” of thickness in this region.
 - There was no evidence of cracking on either the broken or unbroken edge on the test piece.

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- RQ reported that previous HIFiRE tips have all been requested with an “unbroken” edge, and some small cracking was even observed on HF5a nosetip following coating, but have not shown issues on recovered hardware.
 - Brad decided to request “unbroken” edge on the final BOLT tip for these reasons:
 - The 0.010" radius created by their breaking of the edge, following coating, is larger than desired
 - Their testing of the unbroken edge on the BOLT nosetip revealed no cracking (I will confirm again)
 - RQ previous tips did not have broken edge and no observed issues to date, including on recovered hardware
 - HF5a appears to have even flown with small cracks at the rear edge and it still did not cause an issue. Temperatures and pressures are much lower in the back region (even on BOLT, the end of aft swept flight leading edge temperature is ~450C which is below the 700C post-application heat treatment of the coating).
 - Directed Ultramet to proceed with coating of part “A” which they have, which is the primary nosetip. They also have a “B” secondary nosetip in case there are issues with part “A”.
 - Instrument Procurement
 - Call with Medtherm on 3/7/2019. Medtherm verified again that 5/1 is the expected FINAL delivery date for all sensors. They have sent an initial partial delivery to APL of 8 sensors (2 of each type ordered) which will enable APL to measure diameters as delivered. They have ordered all material for the final batches of sensors.
 - Vatell reports “Vatell is not in production yet (but we are getting close to resolving all the production issues)” via e-mail on 3/11/2019
 - Received final shipment of Kulites. Now in possession of 56 Kulite XCEL-100 sensors... 48 of which are planned to fly. Scanned and archived all Kulite shipping receipts and calibration documentation.
 - Thermal Analysis of Fairing and TSM
 - Completed final transient thermal simulation of fairing and TSM with corrected cold-wall heat fluxes and recovery temperatures.
 - Ran ascent case, followed by soak simulation to allow the temperatures to equilibrate, then re-initialized descent to the bulk temperatures of each component following the thermal soak run (for the TSM this was 415K initial temperature prior to descent)
 - The temperatures for the three components, with a 1.2 safety factor on fully turbulent heat transfer were:
 - End of ascent (30.5s):

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- TSM (min, max, bulk): 407K, 580K, 475K
 - Fairing (min, max, bulk): 410K, 520K, 443K
 - End of descent (488s):
 - TSM (min, max, bulk): 317K, 457K, 413K
 - Fairing (min, max, bulk): 332K, 446K, 389K
 - Shared flow solution files with Nick Bisek at AFRL so he can do quality checks on the APL solutions and compare against independent solutions with Overflow.
 - Budget
 - Continuing to monitor and refine spending projections during fabrication and instrumentation phases, as labor burn rate data is gathered, and revised fabrication schedules are provided.
 - PI is following up on some old hardware (Kulites and PCB orders) that were ordered as the wrong cost category. These orders were over-burdened slightly with overhead costs as a result. Post-expenditure adjustment paperwork is being processed incrementally to adjust the cost categories and refund the overhead back to the BOLT budget.
 - Secondary Experiment
 - Received Scott Berry's choice for qty 8 (of 24) Medtherms on secondary experiment that will be single-channel (front face only). The remaining 16 locations will be dual channel measurements.

3/15/2019 through 3/28/2019

- Upcoming dates/milestones:
 - 1 April 2019 – Flight Research Vehicle CDR
 - COMPLETED – completion of primary experiment surface with all instrument holes, ready for instrumentation
- Fabrication
 - Fixturing hardware for main surface external contouring completed 3/20/2019
 - EDM outer contour completed 3/21/2019
 - EDM practice instrumentation holes completed 3/22/2019
 - Used pins to check breakthrough of Medtherm holes to the interior access counterbores. Every hole broke through correctly on the EDM model, and we gave the go ahead to build the final hardware piece.
 - Used precision pins to check diameter of all EDM instrumentation holes
 - Medtherms came within requested tolerance 0.0620 +.0010/-0.0005. The 0.0625 pin went through, while the 0.063 was sticking. So the holes are likely somewhere in the 0.0625" diameter region.
 - Primary surface contour completed evening 3/22/2019
 - A GoPro was provided to the machinist by the APL video team to film the machining of the primary surface outer contour for future PR opportunities

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- Primary surface exterior instrumentation holes completed over the weekend ~3/23/2019
 - Secondary surface contour began 3/25/2019 and completed ~3/26
 - Thanks to Tom Wolf for driving into work at 9pm on a weeknight to view/approve the roughness rear step cut on the EDM part before it was duplicated on the final piece!
 - Gutter fixturing hardware done 3/27
 - Gutter inner contour was nearly completed as of 3/28
 - Mechanical Design
 - Minimally- and heavily-instrumented gutter final CAD and drawings released to machine shop on 3/25/2019
 - Designing to fabricate dummy “Vatell” and “PCB” sensors so we can check the counterbored hole depths on the final parts, since we still do not have these instruments here. We will be verifying that the thickness of the wall at the sensor location is sufficient that we’ll be able to shim the gauges flush, without being too thick.
 - Made cosmetic changes to gutter/sidewall that will enable better filling with RTV. We had concerns about filling the large access cutout region with RTV (the region where the keys fit through to tighten the frustum-to-isolator bolts). We’ve modified this region to create a milled pocket, and a custom plug with a threaded bolt connection will be placed here to recover most of the gutter contour. This plug allows a much smaller, round hole, which will be plugged with RTV.
 - To conserve non-essential cost spending, mechanical design of the fairing has been slowed pending receipt of the next funding increment.
 - Ultramet Iridium Coating
 - Ultramet completed surface polishing testing on the test piece nosetip, which began with a 35-50 microinch RMS finish after the coating application.
 - Post-polishing, they were only able to achieve RMS surface finish in the 19-32 microinch range. 15 locations were measured and the average surface finish was 25 microinches following the polishing.
 - Ultramet held off beginning the final coating until APL could review the surface roughness inspection report from the test piece. They also sent some photos of the test piece after polishing. A tool mark line was visible beneath the coating, and also on the flight hardware tips, right at the tip of the nose.
 - As it was difficult to tell from the photos the smoothness of the test tip, Ultramet sent the tip to APL via FedEx priority overnight and APL was able to receive it the following morning (3/20).
 - APL received the test tip and viewed the surface finish, in particular the line artifact at the tip. We surmise that the line artifact at the tip is related to the
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- tool path used for cutting and the presence of a small “flat” on the nosetip in the geometry.
- APL considered directing Ultramet to do some hand working of the nosetip tool line, but decided against it for these reasons:
 - Significant risk of hand working by 3rd party to cause damage on “shoulder” of leading edge, closer to the sonic line, where surface finish was actually very good in the test piece.
 - APL CFD calculations show even the peak 32-microinch RMS roughness is well below levels expected to affect transition via typical correlations ($Re_k=12$, 40% PANT). All in all, the surface finish on the test piece (in the 20’s) was pretty good.
 - Spreadsheets documenting the “factor of safety” of the as-measured worst-case surface finish (32 microinches) versus the correlations are available on request.
 - Even for the highest Reynolds number (end of descent $Re_L=20e6$, for a cold-wall CFD simulation at 400K, $FoS>1.4$ for $Re_k=12$). Estimated FoS at end of flight when nosetip temperature $\sim 1000K$ is used is >8.4 . These numbers are for worst case 32 microinch finish on the test piece.
 - The baseline surface finish of the final pieces was visually better than the test piece, because the final tips were made afterwards and the machinists were experimenting with tooling paths to achieve better surface finish on the TZM.
 - Ultramet provided photographs and “as-received” and “after surface prep” reports of the surface finish of the final tips (Serial numbers A and B). The reports indicate that post-CVD polishing may be able to recover the as-received finish which was in the 10’s and low 20’s over most of the part, including 2 of 3 measurement locations on the very front of the tip.
 - Ultramet reported completed coating on final nose on 3/26/2019
 - Reported that “visually it looked good”
 - APL received inspection report on coating thickness for the part, with good numbers. The coating is thickest on the nosetip and swept leading edges, towards the upper range of the requested 0.002”-0.004” thickness.
 - Ultramet released the part for polishing and post-polishing roughness tests, along with dye penetration testing to look for coating cracks.
 - Thermal Analyses
 - Fairing CFD data comparisons are still underway between APL and RQ (Bisek).
 - Dave Adamczak reports that RQ re-ran the thermal model with APL heating inputs and found similar temperatures on the TSM to the APL thermal results.
 - CFD/Stability

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- Trying to run some AEDC Tunnel 9 cases with existing grids and scripts (minimal effort) to support future test planning efforts. Of particular interest is the second-mode N-factors at Mach 10 versus previous cases at Mach 5-7.
 - Ground Testing
 - NASA working on requested data analysis from fairing test
 - APL is advising Tunnel 9 on background of the BOLT project as they plan procurement of a model for the future BOLT testing.
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 6 of 172, 140 planned for flight test
 - Vatell: received 0 of 16, 1 ordered, remaining 15 on hold pending resolution of production line issues

3/29/2019 through 4/11/2019

- Upcoming dates/milestones:
- DLR CDR held 1 April 2019, along with follow up call on 8 April 2019.
 - DLR wrote a formal CDR document which describes the meeting. Brad has requested the document and will share with the team if DLR is okay with sharing it.
 - The follow up telecon had some discussion of methods we can use to locate the payload, which will be difficult to spot in the landscape after impact. We need to locate the payload to retrieve the PCB data stored onboard and also the camera footage stored onboard.
 - We discussed various options but nothing was finalized, including a smoke system, streamers, and additional tracking methods (satellite which costs money). Emergency locator transmitter.
 - Brad sent an e-mail to various groups around APL to solicit ideas for tracking and received inputs including RF transmitters (wildlife tracking), search and rescue animals (dogs), and hiker or skier locator beacons. Of the three the most feasible and cheap option seems to be the RF transmitters.
 - DLR and RQ are working on concepts for timing synchronization signals to sync the experimental data systems with the DLR GPS and IMU position data, so that post flight the sensor data can be matched and synchronized with the vehicle position and attitude.
- Fabrication
 - Gutter inner contours completed 4/2
 - Gutter fixtures completed 4/2
 - Quotes for MP35N high strength bolts received - \$1500, 4-5 week lead time, for quantity 12. These bolts were recommended by our structural analyst and were ordered for attaching the frustum to the isolator.

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- Test gutter fit checks with primary surface were completed 4/8, adjusted the locating slot prior to final cut
 - Final heavily instrumented gutter assembled with primary and secondary surfaces on 4/8.
 - Sparsely instrumented gutter final contour cut 4/9.
 - The aluminum surfaces and gutters are now finished, and work has shifted to putting them together as an assembly. Because of the tight fit, some non-critical internal features on the gutter pieces are being hand worked to reduce some radius interferences that were initially preventing the two experiment halves from closing completely. The gap was initially ~0.010" and was reduced to ~0.004-0.007" by mid-day 11 April and to ~0.002-0.003" by late in the day on 11 April.
 - Received our first Vatell gauge! We were able to check all 16 Vatell holes to ensure that the gauge is sufficiently flush with the surface. We designed the holes such that protruding gauges could be shimmed, and added enough margin to ensure that the gauges were not recessed.
 - Mechanical Design
 - After discussions with RQ, decided to scrap plans for internal insulation on the aluminum frustum hardware. Internal insulation was not used on HF5b. Not planning to use on BOLT. Dave reported that the insulation (Cork) caused some issues on previous flights and the complexity to add the internal holes would be time consuming. On BOLT the thermal mass of aluminum is ~31.5kg as opposed to ~21kg on HF5b, so the heat should have much more volume in which to soak and equilibrate.
 - Ordered copper rod dia. 0.0606" +/- 0.0001" from Arrow Grinding Inc. for practice Medtherm installations
 - Holding weekly planning telecons with GoHypersonic to plan the design of the Flight Geometry and TSM/PSM assembly stand. APL and GHI are iterating on a design that will properly support the Flight Geometry and minimize risk of damage during assembly with the TSM/PSM.
 - Ballast 22.3 kg fabrication order placed, to enable material to be ordered. But design is finalized and fabrication will begin as soon as the material is received.
 - Ordering material for the isolator (requested enough material to make 3 parts). Fabrication is on hold pending inspection of the nosetip joint and the frustum joint.
 - Inspection
 - Met with REDD Materials group who owns a few machines we are interested in leveraging for inspection. X-ray microtomography and laser scanning are potential options for characterizing surface shape. CMM for joint steps.
 - Neither x-ray tomography nor laser scanning will get much better than 0.001" accuracy, however the laser scanning setup is relatively cheap so we are exploring getting a laser
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scan. The materials group has the test BOLT nosetip to see if their in-house laser will measure with the reflectivity of the surface.

- Met with the machine shop inspection department for planning CMM measurements of the joint plane. We will first obtain CMM contours of the flight TZM tip with the inspection department, early in the week of 15 April. They will be able to locate the central alignment pin and outer tabs, and then provide a digital point cloud of the as-coated nosetip outer contour. The coating adds ~0.002" of thickness. The data will be used to help size the isolator part to match the as-built tip contour.
- If the joint plane CMM works for the tip, we will attempt something similar for the aluminum frustum assembly joint plane. However because the outer contour is the opposite direction it will be more difficult to measure the aluminum side of the isolator joint with the CMM contact needle which is cylindrical.
- We also plan to use molds at discrete points for surface finish characterization. Ultramet already did their own measurements on the nosetip but we will confirm some of these. The molds can be sputter coated and examined with optical techniques.
- Ultramet Iridium Coating
 - The coating on the final nose tip was successfully applied
 - Ultramet completed an initial polishing of the tip on 4/1/2019, and initially polished only to ~40 microinches RMS. APL requested that they complete another round of polishing to get the surface finish smoother and provided Ultramet with a slide showing critical regions of the nosetip for surface finish.
 - Ultramet completed a second round of polishing and provided the new inspection report on 4/8/2019. The numbers after the second round of polishing looked really good.
 - The critical regions of the main leading edge radius and the swept leading edges measured between 13-22 microinches RMS. The peak surface finish was the machining line directly on the center of the nose at 32 microinches RMS. These numbers, while not as smooth as the cylindrical nosetips on HIFiRE-1 (~12 microinches) are very smooth and well below Re_k=12 or PANT correlations for the flight experiment conditions.
 - APL gave the OK to Ultramet to release the final nosetip and ship it back to us.
 - The coated flight nosetip and uncoated spare arrived to APL on 10 April. The tip looks great!
- Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 6 of 172, 140 planned for flight test
 - Medtherm reports that delivery will NOT be completed by 1 May. They said on 11 April that "mid May" is likely. However, they report that they are actively building the gauge materials.

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- Vatel: received 1 of 16, remaining 15 on hold pending resolution of production line issues
 - Received our first Vatel! It looks like an uncoated HFM-8 E/L but the calibration certificate lists the gauge as an HFM-8 E/H with a coating. We think it's a typo, but are confirming with the vendor.
 - PCB sensors: GoHypersonic reports that the 4-week lead time of the PCB sensors jumped to a 10-12 week lead time! Thus the PCB sensors aren't due to GHI until mid May. We told them it was okay, since this was currently only the third most worrisome delivery timeline of our remaining sensors.
 - Thermal Analyses
 - RQ is re-running TSM temperatures and finding similar numbers to APL results. Dave is re-running the stress analysis but it seems that cork will not be needed on the TSM.
 - CFD/Stability
 - Step CFD results shared by Matt Tufts and Nick Bisek at RQ. RQ is looking at the secondary experiment surface streamlines and pressures compared to the smooth side.

4/12/2019 through 4/25/2019

- Upcoming dates/milestones:
 - 3 May – DLR ACS review (?)
- Fabrication
 - GoHypersonic discovered a mistake in rear fairing bolt hole angles on one side of the aluminum frustum. The two main surface aluminum parts were put back on the machine to add corrected holes on the base of the part in a different location for the fairings. While the parts were back on the machine, we added 3/8" threaded holes at a 90-deg angle to the base (qty 4 total) for GHI's assembly stand, which gives locations to mount hardware to the Flight Geometry for improved handling and lifting.
 - Ordering the tungsten ballast material has been delayed due to the vendor quoted prices exceeding the \$5K limit for credit card purchases. We've reached out to another vendor and if the price is below \$5K, we will order on a credit card, otherwise if it is above \$5K we will have to go through the standard lab procurement process which takes a week or two. It is estimated that the tungsten will have a 30 day lead time on top of the procurement time.
 - Following CMM measurements of the tip and frustum joint contours and alignment features, some test plates are being manufactured for fit checks. These will be simulations of the isolator joints and used to test processes and machine programming used to create the final joint steps.
 - APL received from GoHypersonic a sample PCB heat sink to be used for fit checks of the as-built holes. Verified that the PCB heat sink fits into several of the machined holes on

the BOLT hardware. The hardware protrudes from the surface as planned, so that shimming can be used to bring the sensor back flush to the surface.

- Inspection
 - CMM measurements of nosetip joint completed 4/16 and again on 4/22 with a refined procedure. CMM measurements of the aluminum frustum assembly completed 4/24.
 - Blue light scan of TZM tip and the aluminum frustum completed with ATOS Triple Scan 16M (<http://www.capture3d.com/3d-metrology-solutions/3d-scanners/atos-triple-scan>) with accuracy of 10 micrometers.
 - Following the scans, various methods were tested to align the point cloud with features on the joint. For some of the scans, the alignment was successful, but for others it was marginally successful. Challenges include lack of a proper reference datum and resolution of fine features such as the interior of holes, or edges.
 - Reached out to Direct Dimension, a local inspection company, for quote on accurate measurements of BOLT and the joints. The hope was that the external route may be more cost effective. However, the company responded to our request saying they were not able to provide us with the accuracy that we were requesting on the parts.
- Mechanical Design
 - Major ongoing efforts by Tom Wolf to coordinate inspections of as-built nosetip and frustum hardware so that the final stainless steel isolator part can be released for fabrication.
 - Fairing conventionally machined concept created for cost estimates to shop. The conventional fairing weighs 2.8kg per fairing vs 0.6kg per fairing for the additive option. The challenge is milling out as much material on the odd triangular shape.
 - Discussing with the APL additive group about material properties for additive metals that could be used for the fairings. Potential leverage of that group to provide independent flight qualification analyses and/or testing.
 - Held the last of weekly planning telecons with GoHypersonic to plan the design of the Flight Geometry and TSM/PSM assembly stand. APL and GHI are iterating on a design that will properly support the Flight Geometry and minimize risk of damage during assembly with the TSM/PSM.
 - The conceptual design presented by GHI was agreed upon by all parties.
 - GHI will fabricate holder plates that will allow the Flight Geometry and TSM/PSM to be held and rotated on a fixture during assembly.
 - APL will build an additive polycarbonate negative of the Flight Geometry to insert into the GHI apparatus. The insert will be lined with felt and will hold the Flight Geometry on the aluminum surface so that static loads are not transferred to the joints during handling and/or shipping... with potential risk of damage to the joints.

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- GHI will use the new added lifting holes at the base to hold the Flight Geometry, long threaded rods will connect two plates together.
 - APL and GHI agreed upon conceptual design on 4/19 with minor changes:
 - Increase base area to overhang and protect swept leading edges
 - Provide nominal holding location between rows of sensors
 - GHI to complete final design, send CAD to RQ and APL for final review before fabrication
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 6 of 172, 140 planned for flight test
 - Vatel: received 1 of 16, remaining 15 on hold pending resolution of production line issues
 - Vatel confirmed sensor we received was an uncoated HFM-8 E/L and sent corrected calibration certificate via overnight courier
 - Vatel reports they will be back in production “soon”
 - PCB sensors: received test fit heat sink assembly from GHI

4/12/2019 through 4/25/2019

- Upcoming dates/milestones:
 - DLR ACS CDR – 29 May via telecon
 - Week of July 22nd (?) – Potential science team meeting @ JHU/APL to view hardware, perhaps combined with BOLT II CoDR?
- DLR Attitude Control System (ACS) PDR
 - Held via telecon Friday 5/3
 - DLR presented initial performance of ACS system
 - Even with 2-deg IMU error assumed, the AoA/yaw angles shown by DLR in simulations were very low (under 1 degree)
 - DLR’s analysis was freshly completed, and they do want to check pitch/roll coupling that might occur towards the end of flight due to the increasing dynamic pressure causing the pitch and roll rates to get closer together... they plan to investigate this fully by the ACS CDR.
 - Telemetry Reception
 - DLR confirmed that a second telemetry receiving station was initially not in the budget, as this second station is standard at Andoya
 - Ivett requested proposal from DLR to include the mobile TM tracking station for redundancy in the telemetry reception at Esrange
 - Timing Signals
 - DLR presented timing signal and clock correction standard in their systems (position data)

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- Agreed that simplest approach will be to output the DLR reference pulse timing signal and record it in the RQ experiment data systems, so that post-flight the experiment data time can be corrected for clock drift and synced with the DLR data
 - Fabrication
 - Using CMM data, the machinists completed a series of isolator joint fit check pieces for both the nosetip and the frustum joint
 - Upstream joint
 - Fit check piece completed and we believe it aligns within 0.001" on all four quadrants
 - The cold-wall step will be added in the final part
 - Downstream joint
 - The nominal frustum joint alignment on the isolator fit check piece has been completed.
 - This joint was designed to align nominally with the primary experiment surface side, and accept the assembly tolerance errors on the secondary experiment step side (on the order of a few thousandths of an inch).
 - As estimated with a feeler gauge on the primary side leading edges, we are aligned within 0.001" on both leading edges and main surface on the primary side.
 - The secondary step difference from the primary side CDR nominal value was 0.014". Adding the final 0.007" step would create the 3X step value nominally of 0.021".
 - As estimated with a feeler gauge from the fit check piece, the measured difference was 0.018" on one side and 0.013" on the other side of the secondary experiment. If this alignment holds true for the final piece, it would result in a 3.6X step on one side and a 2.9X step on the other side of the secondary experiment.
 - The isolator is currently being fabricated
 - Some initial troubles with breaking drill bits in the through holes for instrumentation feedthrough
 - The downstream face features were cut first and completed as of 5/8
 - The next step is to flip and cut the outer contour combined with the upstream face features
 - Ordered material for tungsten ballast... expected arrival end of June
 - Inspection
 - Continuing to seek input for desired inspections or characterization of the hardware before it leaves APL in late summer!
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- Received surface finish points from Minnesota / John Thome – thanks!
 - Received general desire to take CMM measurements on or near the nosetip curvature region from Steve Schneider
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 - Mechanical Design
 - Fairing
 - Received from Dave Adamczak example testing reports from previously flown additively manufactured parts
 - Met with additive group to review existing data on the Elementum additive aluminum. The company sends materials out to an independent review for testing... some data are available, other data will be requested
 - Requesting conductivity in z-direction and in x-direction
 - We have material strength versus temperature data in the z-direction
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 6 of 172, 140 planned for flight test
 - Vatec: received 1 of 16, remaining 15 on hold pending resolution of production line issues
 - Vatec reports they will be back in production “soon”
 - They are aware of our desire to order 16 (15 plus one spare) as soon as they return to production
 - Vatec says the lead time will still be 4 weeks for the order once they are returned to production (that is good!)
 - PCB sensors
 - GHI has received the PCB sensors as of 5/2
 - GHI plans to install the PCB sensors in the heat sinks over the next 1-2 weeks
 - Asked GHI and/or Matt Borg to verify that the PCB sensors do not have the same quality issue that Brandon Chynoweth observed several months ago (curvature on the front face)
 - GHI has completed a few of the initial RTV steps to install a few sensors into the heat sinks

4/26/2019 through 5/16/2019

- Upcoming dates/milestones:
 - DLR ACS CDR – 29 May via telecon
 - Week of July 22nd (?) – Potential science team meeting @ JHU/APL to view hardware, perhaps combined with BOLT II CoDR? Possibly to be delayed depending on funding gap resolution (?)
- SciTech 2020 Papers

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- Worked with Fluid Dynamics TC to carve out a “special session” which may turn into 2 sessions if we end up with more papers.
 - Thus far received confirmed plans for these BOLT-related papers at SciTech:
 - Brad Wheaton, Dave Adamczak (JHU/APL and AFRL/RQ - Flight experiment design and flight overview)
 - Scott Berry (NASA LaRC, secondary experiment overview and related analyses)
 - Helen Reed (TAMU, stability)
 - Thome/Candler (Minnesota, topic TBD maybe roughness)
 - Kostak/Bowersox (TAMU, Wind Tunnel Experiments)
 - Brandon Chynoweth (Purdue joint step testing)
 - Beth Rieken (NASA LaRC, fairing and TSM aerothermal testing)
 - Nick Bisek (AFRL, joint steps CFD)
 - APL and RQ completed public release review and submitted abstract for the overview paper on 16 May
 - Communications between Brad, Scott, and Brandon regarding the documentation of the joint step testing, secondary experiment, and related analyses between the three respective papers.
 - Fabrication
 - Completed initial “good” isolator in early May and currently working to evaluate if the as-built joint steps are close to desired
 - Completed assembly to install isolator onto frustum - it fits
 - Need to loosen up clearance holes on the isolator for the bolts connecting to the nosetip as they are slightly tight preventing the nosetip from bolting onto the isolator. Note these are the bolt clearance holes and are not the aligning features on the nosetip joint.
 - We are at a decision point as to whether to cut/fabricate a second “good” isolator
 - We have one more block of stainless material but the second isolator would probably take 2-3 days of machinist labor so it is a cost question
 - Thus far we think the first isolator is probably going to work for the final version, as the steps appear close to desired, but we might want to make a spare, or change the step height (isolator length) slightly for a new version as we obtain more quantitative information on the steps as built.
 - Status on remaining components:
 - Ballast: awaiting delivery of tungsten ca. late June. Fabrication will likely be held depending on funding increment delivery timing.
 - Fairings: on hold pending final analyses on additive materials (thermal, structural), results of these analyses will be briefed to the team before fabrication is authorized. Work on the fairing is on hold pending funding increment delivery timing.

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- Ordering support hardware as we go along (bolts, etc.)
 - Instrumentation
 - Identified staff member (Nate Allen) who will be trained to install the Medtherms this summer. Nate is an experimental machinist at APL and is very excited to be involved on BOLT!
 - Received copper rod from Arrow Grinding, diameter 0.0606+/-0.0001" at a total of 36" length, that will be used for the first round of practice installations. The diameter of the rod matches the measured diameter of as-received Medtherms.
 - Arranged for an initial meet and greet / training for Medtherm installations with AEDC Tunnel 9 on 5/21. Thanks to George Moraru for coordinating and John Lafferty for allowing his technician to consult and advise APL as we get up to speed on the tips and tricks of installing these Medtherms.
 - GHI is completing initial RTV installation of PCB sensors in the heat sinks. APL shipped the 10th heat sink back to GHI since it was no longer needed for fit checks. There will be 8 primary heat sinks and 2 spares.
 - Inspection
 - Inspection efforts have been mainly focused on the new as-built isolator part as we assess how closely we matched the joint steps were aiming for.
 - The isolator was initially examined after installation to the nosetip and frustum via feel using shim measurements at various locations of the upstream and downstream joints. Precision shim stock and feeler gauges were used and placed flush to the joint, and fingernail assessments to determine the joint height range. From these initial assessments we became confident that the first isolator was in the correct range of step heights desired.
 - Arranged for APL's professional photographer to take photographs of the installed joints using reference thickness shims in close proximity. These photos were completed on 16 May and are currently being post-processed for delivery.
 - The photos were taken by a professional to obtain good lighting, resolution, and field of depth in order to focus the edge of the reference shim with the joint.
 - Photos were obtained on all four quadrants, on all four joints, and on the main surface and gutter surface.
 - The photos will be analyzed using open source image analysis software from NIH ("imagej") which will be able to measure pixel distances.
 - If this process is successful we would plan to repeat the photographs on the final assembly so we can measure the "as-flown" joints.
 - Checked on blue light scanner availability
 - The scanner has disappeared into the closed area
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- However, the group at APL that owns the blue light scanner is working on a process to be able to remove the machine for occasional random unclassified scans.
 - We decided to check back in the August 2019 timeframe to see if that process has been defined, at which point we would obtain a blue light scan of the “final assembly” after instrumentation is complete.
 - Mechanical Design
 - Fairing
 - Met with additive materials group on 7 May to assess what data we have on material performance
 - We have material strength versus temperature plots for the Elementum additive 6061 material (this is good!)
 - The thermal properties are available in the build direction, but not as a function of temperature
 - Will want to re-run the APL fairing and TSM thermal model with the additive aluminum conductivity and specific heat properties to compute new temperatures, although they are expected to be low
 - Asked RQ for fairing pressure loads and received on 16 May (thanks Jim Tancred!)
 - Path forward for closing aerodynamic fairing material selection identified, but currently slowed pending some funding timing concerns:
 - Obtain all available thermal conductivity and specific heat data from manufacturer’s independent test firm (request to be made)
 - Run APL thermal model of fairing and TSM with new thermal properties to compute new temperature distributions at peak load cases (max Q ascent and descent end of experiment)
 - Apply max aerodynamic pressure to SolidWorks FEM model of the fairing with representative structural connections
 - Compare peak stress and localized strength at temperature and report factor of safety on yield and ultimate
 - Brief results to team for go-ahead to complete fabrication/build
 - APL group to print test coupon materials alongside final build to examine build quality
 - Thermal Analyses
 - Assembled Fairing and TSM thermal slides for 29 May DLR ACS CDR (action item from ACS PDR). The slides are in the public release review process at APL.
 - Communications with Dave Adamczak to share peak and bulk temperatures of TSM from two thermal models (they compare very closely)

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- Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 6 of 172, 140 planned for flight test
 - Medtherm reports next batch of 36 sensors will ship on 16 May!
 - Medtherm reports another 25 sensors are to follow close behind that shipment
 - Vatel: received 1 of 16, remaining 15 on hold pending resolution of production line issues
 - Vatel still has not been in touch to confirm when production will be back
 - PCB sensors
 - GHI is nearly finished with the installation of PCB's in the heat sinks

5/17/2019 through 6/6/2019

- Upcoming dates/milestones:
 - Week of July 22nd (?) – Potential science team meeting @ JHU/APL to view hardware, perhaps combined with BOLT II CoDR? Possibly to be delayed depending on funding gap resolution (?)
 - August (late?) 2019
 - RQ to test sensors w/ data systems prior to assembly on site at APL (?)
 - Final integration @ APL
 - Final inspection @ APL
 - September 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - September-October 2019 – Payload Integration @ AFRL
 - October 2019 – Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @ Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
- DLR news
 - S31 motor delivery is confirmed and will be latest October 2019
- Held DLR ACS review on 29 May 2019 via telecon (DLR, Ivett, Brad, Dave A.)
 - Brad's notes:
 - Potential mismatch in interface dimensions between the built PSM and the DLR components. It seems the error could be small enough that the pieces still fit. DLR will send an interface fit piece check to RQ ASAP, pending export approval, so RQ can check the fit.
 - A solution has been agreed upon to sync the timing signals between the DLR flight systems and the RQ data acquisition systems

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- Telemetry link analysis shows that addition of a second telemetry receiving station would add much needed redundancy in capturing the data, especially for the high rate streams from the experiment systems where the margin is suboptimal with just the Esrange tracking station at higher downrange distances
 - Ascent AoA and sideslip angles w/ realistic wind shear profile from other flights were shown. The BOLT analysis shows the ascent angles remain quite low <0.25 deg when adding a wind shear disturbance, but DLR cautioned that other disturbances will exist that can't all be modeled. Previous flight data suggests 1-2 deg. angles are more likely for ascent.
 - DLR has performed 6DOF analyses of descent phase and identified a "high risk" of coning occurring near the end of flight, at very low altitudes, with onset nominally after the conclusion of the descent experiment
 - This occurs due to the convergence of roll rate and natural pitch frequency (which is a function of moment of inertia, pitching moment slope vs AoA a.k.a. Flight Geometry shape, and dynamic pressure).
 - Because we have defined an end of experiment flight altitude slightly lower than the HIFIRE-5 (16km vs 18km) the risk of coning is more prevalent as the dynamic pressure increases quite rapidly
 - DLR performed a trade study of fin cant angle versus risk of coning at end of flight. A 0.3-deg cant angle was chosen for the 2nd stage fins. This angle was a balance to keep the predicted coning onset after the end of the descent experiment, but not set the angle too high that coning becomes more risky during ascent.
 - The coning is predicted to occur after end of experiment, nominally, but uncertainties in modeling are likely +/- 1-2 seconds. Brad assessed the worst-case if coning begins 2 seconds earlier and it still seems likely that the flow would be fully turbulent by that point.
 - DLR has temperature concerns on the manacle ring connecting the DLR service module with the DLR motor adaptor. DLR suggests applying cork to mitigate these concerns, which is a reduction in strength but also a potential differential thermal expansion which could loosen the manacle ring prematurely.
 - Official DLR ACS CDR action items (from Ivett 6/6/2019):
 - The latest fairing is not shown in the DLR pictures – calculations were done with correct fairing but would be nice to have the right picture – Brad will send the correct fairing to DLR (.step)
 - Are there wind limits for launch for BOLT II? -- DLR
 - Confirm fin can angle for slide 12 is 0.3 deg – DLR
 - DLR to look for wind data for OST2 flight and corresponding fin settings

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- Need to correlate slide 13 to actual wind conditions
 - Manacle ring needs more thermal analysis
 - Slide 10: DLR to send to RQ blank to verify interfaces
 - Dave to send DLR drawings for interfaces so we have detailed drawings of all the interfaces
 - Ivett to set telecon with NASA Wallops on recovery system to decide if we will add their system
 - Ivett to work with Doug Dolvin on export control for the flight for both Germany and Sweden
 - DLR to do a sensitivity analysis with 20% on all aero coefficients to see what change that has on pitch-roll coupling with fin can angle of 0.3 deg. Dave assesses the error/uncertainty on his aero coefficients is 20%
 - DLR to complete their internal thermal analysis
 - Dave to check for HIF5/5b AoAs during the experimental phase on re-entry (Dave to send already published papers on this and DLR can use the data to validate their own computations for the trajectory)
 - Fin cant angle of 0.3 deg is the chosen value unless the margin calculations (last bullet above) show something different
- Inspection
 - Photos of step heights of isolator analyzed. Assessments to be reported on 6/7/2019 telecon slides.
 - The step heights were assessed at the tangency points created by the leading edge interface, as the point of identical optical perspective with the reference shim edge
 - Fabrication
 - Evaluated Isolator and determined to move forward as the final flight part
 - E-mail summarizing the decision making process went out on 6/6/2019 and documentation of decision also captured in slides presented at 6/7/2019 telecon. Abbreviated reasoning to follow here.
 - Determined that primary side steps within 0.0005" maximum of aim points on downstream joint and 0.001" maximum of aim points on upstream joints
 - Observed assembly tolerance errors (horizontal shifted offset and slight part gapping) resulted in secondary side step variations closer to 2X and 4X than the nominal 3X aim point on the swept leading edge
 - These measurements are preliminary and assessed via photogrammetry
 - Final measurements of the joint steps to be made again after final assembly via all methods (blue light scan, CMM measurements, photogrammetry) to document the flight steps.

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- The team offered to hand work the frustum assembly a bit more in order to get the secondary side steps a bit more even, but the PI decided to move forward with the first isolator for these reasons:
 - Effort and spending already undertaken for inspection, test fit pieces, and fabrication challenges to make one “good” part
 - Risks that we could worsen the fit or otherwise damage the frustum pieces, resulting in worse primary side steps than the initial attempt
 - Satisfaction with symmetry and magnitude of all cold wall steps on the primary side
 - Fairing Additive Aluminum test parts completed by additive group
 - To test fit of fairing to base of Flight Geometry (particularly the aft-facing step desired)
 - Also for future research (not supported by BOLT budget):
 - “dog bone” samples for yield strength testing
 - Test coupons for thermal conductivity, specific heat, and CTE
 - Awaiting manufacturer data on thermal properties, otherwise will run fairing thermal sim with the quoted properties
 - Mechanical Design
 - Tom Wolf took a much needed VACATION!
 - Instrumentation
 - Nate Allen, Brad Wheaton, and Tom Wolf went to Tunnel 9 for a Medtherm installation training meeting 21 May 2019
 - Spent a couple of weeks doing trial installations and developing processes for installing Medtherms, using practice copper rod
 - We are receiving sporadic batches of Medtherms that are permitting installation!
 - Vatell is up and running and we are trying to order qty 16 sensors from them
 - Matt Borg and Brad Wheaton exchanged several e-mails assessing the gains on the PCB sensors for both HIFLIER and BOLT. It was decided that the gains for the HIFLIER flight should be sufficient for BOLT. However there are significant uncertainties in terms of what mechanisms we could see on BOLT, when in flight it would occur (in terms of freestream mean pressure / Reynolds #). HIFLIER has the added bonus of knowing “where” HIFiRE-1 saw transition, and knowing the second mode instability N-factors at those conditions.
 - Completed mapping instrumentation on secondary side to the remaining 4 boards, which was an action item as of CDR. Used Scott Berry’s recommended locations for the single-channel front face only sensors, but advised Scott a recommended swap for two of those locations.

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- Created drawings of locations of sensor types and designations for the instrumentation installer to assist him in selecting the right instrument to put in each hole, and marking the wire with the proper designation.
 - Updated sensor XYZ coordinates. Upon review found a mistake in which board the mean pressure sensors were going to. This mistake would have resulted in wires crossing the two assemblies. The mistake was easily rectified by swapping PLBW sensors to the proper boards of identical type on the other side of the furstum subassembly. Sent corrected XYZ coordinates to Dave.
 - Dave updated the master instrumentation list with the current XYZ coordinates and completed another mapping of sensors to board channels on each board. For example which sensor pair (TLBWXX/YY) will go in the board channel marked (TC1/2).
 - Placed order for Molex connectors, crimp terminals, and fiberglass wire sheathing from Allied electronics so it will be available ahead of integration.
 - Spent a lot of time getting the instrumentation installation machinist set up for work... workspace location, equipment, benchtop multimeter, probe test leads, files, sanding tools, Loctite, hole cleaning brushes, etc.
 - Thermal Analyses
 - Fairing thermal analysis completed assuming conventional 6061 aluminum properties
 - Analysis to be repeated with additive aluminum properties, best available
 - Cleared for public release “jhuapl-fairing-tsm-thermal-final-distA.pptx” and briefed at DLR ACS CDR
 - Fairing findings:
 - Aerodynamic fairing temperatures assuming conventional 6061 aluminum properties are very low, especially at bolt locations close to Flight Geometry aft bulkhead
 - Additive aluminum data from manufacturer’s independent testing has yield strength vs. temperature numbers sufficient for stress analysis
 - Obtained peak aerodynamic pressure loading from Jim Tancred @ AFRL/RQ (thanks!)
 - Ground Testing
 - Reviewed NASA fairing data from LaRC, advised on some data post-processing to average the heat flux from different cases. The end result would be assessment of the APL thermal analysis safety factor on the fairing and TSM grid, and new temperatures could be computed if the averaged heating exceeds the 0-deg heating by more than the assumed amount.
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 42 of 172, 140 planned for flight test
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- Medtherm reports 26 more sensors due ca. 7 June
 - Remaining partial deliveries unknown
 - Vatel: received 1 of 16
 - Vatel procurement held up awaiting paperwork from vendor, requested 21 May but still not completed as of 6 June!
 - Vatel scheduled delivery not likely until 6 August
 - PCB sensors
 - GHI is nearly finished with the installation of PCB's in the heat sinks

6/7/2019 through 7/2/2019

- Upcoming dates/milestones:
 - TBD (?) – Potential science team meeting @ JHU/APL to view hardware, perhaps combined with BOLT II CoDR? (?)
 - August (late?) 2019
 - RQ to test sensors w/ data systems prior to assembly on site at APL (?)
 - Final integration @ APL
 - Final inspection @ APL
 - September 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - September-October 2019 – Payload Integration @ AFRL
 - October 2019 – Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @ Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
- DLR news
 - RQ reports that DLR PSM fit check piece fits!
 - “received the Radax test fixture and was able to test fit it to the PSM. It bolted up with no issues even with the slight dimension mismatch on the hole location diameters. There was plenty of room in the thru holes on the test fixture to the holes in the PSM male flange”
- Fabrication
 - Ballast material arrived 6/18 but job has not yet been scheduled
 - Fairing fabrication nearly ready but on hold pending structural analyses and to see if we can leverage some internal funding to pay for the bulk powder batch order
- Instrumentation
 - Medtherm grounding

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- Observed that 6 of the first 10 Medtherm installs were reading low resistance between the gages and the aluminum frustum, despite following well established bonding procedures
 - Inquired with RQ and T9 re: their experiences before proceeding with further installs
 - Roger Kimmel reported limited spot checking of previous flight installs on HIFIRE 1 and 5b that some Medtherms were electrically connected to the payload, but the majority that RQ recalls checking were not. However, Roger said he looked at previous flight data and saw no discernable difference in the connected and nonconnected gages.
 - Tunnel 9 reports they have tried many methods and have been unsuccessful in isolating Medtherms from test articles, saying they typically do not worry about it.
 - There was no actionable change in procedure identified for further installs, apart from greater care to strain relieve wires and to pay greater attention to ensuring a complete coating of the Medtherms with the Loctite on future installs.
 - Kulite installation procedure
 - Received from Tunnel 9, RQ, and Sandia
 - Currently machining practice rod to precise diameter for practice Kulite installs on the test piece
 - Thermal Analyses
 - Received additive aluminum thermal properties versus temperature from independent test company and running the fairing thermal analysis again with updated temperatures (expecting higher surface temperatures but lower in-depth temperatures due to the slightly reduced thermal conductivity)
 - Inspection
 - Need to formalize inspection plan but roughly as follows...
 - Methods for joint steps
 - 1. CMM measurements of individual joint planes and alignment features (completed on Nosetip and frustum, needs to be completed on isolator)
 - 2. CMM measurements of final assembly
 - 3. Photogrammetry of final assembly with shims
 - 4. Mold measurements of joint steps
 - Per conversation with Brandon Chynoweth, these to be handled by Purdue, with first round when payload is at RQ
 - 5. Blue light scanner (we lost this asset, and we question the quality of this data, thus we will need to discuss dropping this technique)

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- 6. Profilometer (RQ asset, will explore doing something in situ during payload assembly if risk of surface finish damage is deemed acceptable)
 - Methods for distributed roughness
 - Mold measurements at discrete points... need to define these
 - Methods for overall shape
 - Obtain limited CMM measurements during final inspection
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 68 of 172, 140 planned for flight test
 - Received 26 additional on 12 June 2019
 - 34 flight sensors installed as of 7/2/2019, 1 broken (TLBW135)
 - Medtherm reports 40 more sensors due ca. 7 June
 - Remaining partial deliveries unknown
 - Vatell: received 1 of 17
 - 5/23/19 – Vatell indicated ready for production with 16 HFM-8 sensors
 - 6/10/19 – Purchase order finally processed and issued
 - 6/18/19 – Vatell communicates an error and are unable to make HFM-8 sensors. They would be able to make the HFM-7, which is identical except the temperature compensation is done via resistance temperature (RTD) in lieu of thermocouple.
 - 6/20/19 – After exploring options, decided to order the HFM-7 sensors.
 - 6/25/19 – Dave Adamczak completes new board design (Thanks for saving us again Dave!)... board should arrive to RQ a few weeks before sensor delivery to APL.
 - 6/27/19 – Vatell provides calibration sheet for fine tuning gains
 - PCB sensors
 - Received all sensors and associated hardware from GHI on 6/18/19
 - Adam Culler suggests PCB 8607 for practice installation. This was the first one installed in a heatsink. After PCB 8607 was RTV'd in place GHI noticed a tiny burr at the surface of the heatsink ID. Subsequently, they found this burr on all remaining heatsinks, then removed it (with a pin gauge and fine stone) prior to installing the remaining nine PCB's.

7/3/2019 through 7/19/2019

- Upcoming dates/milestones:
 - September 2019
 - RQ to test sensors w/ data systems prior to assembly on site at APL (?)
 - Final integration @ APL
 - Final inspection @ APL

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- TBD (?) – Potential science team meeting @ JHU/APL to view hardware (?)
 - October 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - October 2019 – Payload Integration @ AFRL
 - October 2019 – Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - Hosted AFRL/RQ (Adamczak and Dolvin) 7/17 through 7/18 (also Kimmel on 7/17)
 - Viewed and reviewed progress on hardware and instrumentation installation
 - Dave brought a flight computer and GUI to leave at APL to perform checkouts of sensors by hooking up to the sensor boards.
 - Discussed shipping crates
 - APL to build one crate to hold Flight Geometry, TSM, and PSM.
 - Crate would nominally be wood with foam supports for payload during shipping.
 - Questions about whether to ship with GHI payload handling fixtures attached or detached. Decided that we may want to ship with some of the handling fixtures attached to make it easier to handle during removal from the crate, but that the handling fixtures should not be connected to the crate structure, or should be padded with foam, to reduce risk of damage during shipping.
 - Discussed schedule issues
 - Medtherm deliveries are holding up progress at APL and pushing back schedule
 - Some margin in the integration at RQ, according to Dave
 - Environmental testing is pushing towards November-December holidays which is always tricky, possibly could slip into January
 - DLR still doesn't want the payload until March 2020
 - Discussed shipping and logistical issues
 - Discussed environmental testing
 - Need to get APL and ISSI contacts talking to establish formal costing and schedule for testing
 - Concerns about ability to open up BOLT payload in between tests if isolated problems are found with connectors or boards (BOLT will not be easy to take apart after the nosetip is installed and there is risk to the nosetip instrumentation every time we try to do that.
 - Toured electronics fabrication facilities whose staff will be doing the wiring and connectors for BOLT
 - Instrumentation
 - Status
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- All Medtherms are installed on the secondary surface.
 - All Medtherms are installed on the primary gutter.
 - All Kulites are installed on the secondary surface, secondary gutter, and primary gutter.
 - Began installing Medtherms on the primary experiment surface but are out! Need 71 additional at minimum to complete Medtherm installations.
 - Surface finish process identified and completed on one aluminum assembly
 - APL used test piece to try a variety of surface finish options on the aluminum. Selected 400-grit sandpaper option for consistency with previous flights.
 - Secondary surface finishing completed. APL shop inspector suspects finish is near 8-16 microinches RMS on the frustum which is well beyond surface finish requirement for that part.
 - Here is the process used to attain the surface finish:
 - 1. Wet sand to 400 grit
 - 2. Clean getting off all of the mess from sanding
 - 3. Using a red lapping pad sand till it has an even finish
 - 4. Clean getting off all of the mess from sanding
 - 5. Using a Gray (a finer grit than red) lapping pad sand until it has an even finish
 - 6. Clean with a cotton rag
 - 7. Repeat Using a Gray lapping pad sand till it has an even finish
 - 8. Clean
 - 9. Keep repeating with a gray lapping pad till you get to an 8 finish
 - You may need to start over for deep scratches. The trick is how well you clean it when you go from one grit to the next, keep it clean and free of oil (wear gloves)
 - Following surface finish, each Medtherm is re-scuffed using a protector with a small punch hole at the diameter of the Medtherm, so that the junction can be applied locally on the Medtherm face without scuffing a large portion of the acreage
 - Testing light tack protective films that will be used to protect the surface finish and prevent long term oxidation of the part during storage
 - Established Kulite installation procedure that works well for the BOLT geometry
 - Created a small fixture that protects the sensor face during the application and removal of excess RTV around the sensor face during installation
 - That same fixture is cylindrical and is “rolled” across the flattest portion of the geometry (in the streamwise direction) to ensure that the Kulite sensor face is

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- at least flush with the surface to minimize the risk of the sensor face protruding above the surface and creating a forward facing step.
 - The Kulite installation is more challenging in the gutter which has both streamwise and spanwise curvature
 - Fabrication
 - Ballast fabrication started 7/19
 - Fairing fabrication pending review of analyses on 7/19
 - Fairing design review to be held Friday 7/19/19
 - Thermal analysis complete with new Elementum 6061-RAM2 additive properties... effect on temperature negligible
 - Obtained strength vs. temperature data for the material
 - Completed Solidworks structural analysis assuming conservative aerodynamic loads
 - Peak stress occurs at a pin hole near the external swept leading edge aft of the Flight Geometry where temperatures are highest, but yield stress safety factors maintained throughout flight
 - Safety factors at the bolt locations (structural connection) > 3.6 even at end of flight.
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 68 of 172, 140 planned for flight test
 - Have received NO additional sensors since 12 June 2019
 - 61 flight sensors installed as of 7/2/2019, 1 broken (TLBW135)
 - Medtherm reports 51 more sensors due ca. end of July
 - Remaining partial deliveries unknown, but communicated to Medtherm the required additional types and variants we'd need following the expected 51
 - Vatel: received 1 of 17
 - PCB sensors
 - Received all sensors and associated hardware from GHI on 6/18/19
 - Received high-speed DAQ and enclosure box along with spacers and spare parts on 7/18/2019

7/20/2019 through 8/2/2019

- Upcoming dates/milestones:
 - August 2019
 - Complete all frustum sensor installations (pending 19 remaining Medtherms)
 - Complete wiring and packaging of primary assembly
 - Begin (complete?) wiring and packaging of primary assembly
 - Complete
 - September 2019
 - RQ to test sensors w/ data systems prior to assembly on site at APL (?)

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- Final integration @ APL
 - Final inspection @ APL
 - TBD (?) – Potential science team meeting @ JHU/APL to view hardware (?)
 - October 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - October 2019 – Payload Integration @ AFRL
 - October 2019 – Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - PCB box interference issue
 - Discovered interference with PCB box mounting location
 - Length had increased by ~0.65” in CAD provided 2/15/19 (12 days ahead of CDR), but we didn’t catch it.
 - Designed and manufactured an offset plate to shift the PCB box forward and up.
 - Swapped two boards in the secondary assembly to give better clearance to the PCB box.
 - Took another look at boards on primary side and made one board swap.
 - Fabrication
 - Ballast fabrication completed
 - Have not weighed part as part is too heavy for scale local to machine shop
 - Ended up with a surrogate aluminum ballast which is useful to be installed during the wiring and packaging
 - Fairing fabrication not yet started
 - Wiring and Integration
 - Met with electronics fabrication group. We have a single tech assigned to this project – welcome Liz Roycroft to the BOLT team!
 - Secondary assembly is with the electronics fabrication group to undergo wiring and application of connectors to the 4 boards on the secondary side!
 - Created drawings of sensor hole designations, installed serial number, to the correct board number and channel. Double and triple checked these drawings!
 - Created spreadsheet master for electronics wiring with wire locations and pin numbers.
 - Provided sheathing, connectors, and pins to wiring group.
 - Secondary side drawings and wiring experience will guide and refine the processes we will use for the primary side assembly, which has ~5X the number of boards as the secondary side.

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- We will need to do a lot of experimenting and thinking on how to lay out and orient the primary boards to run the ribbon cables out.
 - RQ status
 - New Vatel boards received, had to fix one issue with a jumper wire
 - RQ Lieutenant finished calibrating all boards, Dave is checking one final time but the boards are almost ready to send to APL
 - Selected engineering units for sensors:
 - Raw digital data always is 24-bit or 16-bit (PMBW) unsigned integers
 - PLBW (kPa), PMBW (Pa), Temperature (deg C), Heat Flux (kW/m²)
 - Dave to start building telemetry processing (TM) code, building words/streams
 - Brad and Dave discussing strategies for common time base of all three TM streams (per Tom Juliano tracking multiple time bases was not ideal for HF5b)
 - Environmental testing funding still moving to ISSI
 - No updates from DLR on launcher move (might be on summer holiday)
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 126 of 172, 140 planned for flight test
 - 61 flight sensors installed as of 8/1/2019, 1 broken (TLBW135)
 - 52 type T sensors received 7/31
 - 6 remaining type E sensors received 8/2
 - 19 remaining type T sensors minimum needed to complete parts
 - Vatel: received 1 of 17
 - Status as of 8/1: "The QTY-(16) sensors are built. The last (spare) is being built. At that time all sensors will complete final calibration & will be ready to ship."
 - PCB sensors
 - All received, awaiting installation (last step)

8/3/2019 through 8/16/2019

- Upcoming dates/milestones:
 - August 2019
 - Receive all instruments (19 Medtherms)
 - September 2019
 - Complete all frustum sensor installations (pending 19 remaining Medtherms)
 - Complete wiring and packaging of primary assembly
 - RQ to test sensors w/ data systems prior to assembly on site at APL (?)
 - Final integration @ APL
 - Final inspection @ APL
 - TBD (?) – Potential science team meeting @ JHU/APL to view hardware (?)
 - Early October 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ

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- October 2019 – Payload Integration @ AFRL
 - October 2019 – Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @Ottostrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - Fabrication
 - Fairing aluminum powder being ordered
 - Wiring and Integration
 - Secondary side wiring completed 8/16
 - Instrument checks on secondary side will commence early next week
 - Pending checkout of instruments wiring will be laced and connectors fixed
 - Created PCB and Vatel maps for eventual primary side wiring
 - TLBW135 back face wire came loose from housing (same sensor front face was broken). This sensor is now a total loss.
 - Working on mapping joint TC's to boards
 - Unfortunately we found that the joint TC's have to split between the primary and secondary side which will further complicate the installation of the nosetip
 - Instrumentation
 - Installed all received Medtherms
 - Medtherm indicates remaining required sensors to ship 8/23
 - Received Vatel's
 - Ordered joint TC wires and internal temperature TC's
 - Environmental Testing
 - RQ funding completed move to ISSI
 - Awaiting go-ahead from ISSI for the ISSI to APL-ETF (Environmental Test Facilities) contract
 - APL to build vibration testing interface plate
 - APL, RQ, exchanging interface drawings for RADAX joint and electrical connectors
 - Dave and Brad to discuss scheduling for November and December
 - Ground Testing
 - NASA completed analysis of TSM heating and determined that roll-averaged heating is bounded by the 1.2 safety factor applied to the 0-deg heating
 - Instrumentation Procurement
 - Kulites: received 56 of 56, 48 planned for flight test
 - Medtherms: Received 126 of 172, 140 planned for flight test
 - 113 flight sensors installed as of 8/15/2019, 1 broken (TLBW135)

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- 19 remaining type T sensors expected to ship 8/23
 - Vatel: received 17 of 17
 - Received on 8/15!
 - PCB sensors
 - All received, awaiting installation (last step)
 - Ordered joint TC wires and internal temperature TC's
 - Joint TC wire
 - <https://www.omega.com/en-us/wire-and-cable/thermocouple-and-rtd-wire-and-cable/xc-k-tc-wire/p/GG-K-24-100-ROHS>
 - 24 AWG fits larger style Molex crimp pins
 - Glass braided 100ft length
 - Rated to 482C / 900F
 - Internal temperature measurements in Flight Geometry:
 - <https://www.omega.com/en-us/sensors-and-sensing-equipment/temperature/sensors/thermocouple-probes/sa1/p/SA1-K>
 - Anticipate 6 total measurements inside Flight Geometry, sites TBD
 - Standoffs, board temperatures, etc.
 - Rated to 175C / 347 F

8/17/2019 through 9/11/2019

- Upcoming dates/milestones:
 - September 2019
 - 16 September - Complete all frustum sensor installations
 - 17 September – Begin wiring primary side
 - 26 September (?) - RQ to test sensors w/ data systems prior to assembly on site at APL (?)
 - 27 September 9am-3pm – Science team meeting @ JHU/APL to view hardware
 - October 2019
 - Complete wiring and packaging of primary assembly
 - Final integration @ APL
 - Final inspection @ APL
 - Early October 2019 – APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - Payload Integration @ AFRL
 - Latest delivery of S31 motor to DLR
 - November-December 2019 – Environmental Testing @ JHU/APL ETF facilities
 - Entry 1
 - 13-15 November: Vibration

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- 18-22 November: Thermal (round the clock)
 - 25-16 November: Vacuum
 - Entry 2 (if needed):
 - 4-6 December: Vibration
 - 9-13 December: Thermal (round the clock)
 - 16-17 December: Vacuum
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - Fabrication
 - Manufactured Vatel shims
 - Additive aluminum fairing builds to begin in mid-September
 - Still need to build additive polycarbonate negative for the GHI assembly rig
 - Instrumentation Installation
 - Medtherms
 - Received last remaining Medtherms needed for flight parts on 28 August
 - All Medtherms have been installed!
 - Following completion of all Medtherms, the primary side frustum finish was applied to the experimental surface
 - Kulites
 - All Kulites were installed in the primary assembly following completion of the Medtherm installation
 - Kulites were inspected for flushness, one Kulite was slightly recessed and had to be replaced. A new/spare Kulite sensor was used although the original sensor still appears functional.
 - The Kulites were inspected against the drawings to verify proper locations of the various types (15 psia and 5 psia)
 - Vatellets
 - Installation of the Vatellets began on 9 September and was thought to be fairly straightforward
 - To account for shimming of the Vatellets, the counterbored holes were designed for a nominal 0.005" shim depth, so all Vatellets were initially installed with this thickness of the shims. A select few sensors were protruding and for these a 0.001" shim was added.
 - We discovered that the "lip" of the housing in some cases is not perfectly parallel to the front face, thus some slight misalignment was noted in the first install.

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- In addition, while the sensor faces are nominally flat, one corner of the face contains epoxy that covers the wire routings from the thermopiles into the housing. This epoxy in some cases was not very flush and protrudes above the sensor face. It was decided to try to install the gages with this epoxy pointed outboard, to use the natural curvature of the BOLT geometry to help create better flushness.
 - The Vateils were all removed and assessed individually for flatness, evaluating both the raised epoxy and the uniformity of the housing lip. The gages deemed of highest quality were then installed in the upstream locations where flushness is most critical. The least “flat” gages were installed at the aft array of sensors, with preference towards the centerline for the worst sensors.
 - In all cases the Vateils were attempted to be shimmed such that any sensor protrusion feature would be recessed, but in some cases we estimate there may be some slight protrusion near ~ 0.001 ". The Vateils are located downstream where the boundary layer is thickest, in most cases with no sensors behind them, so this was deemed acceptable.
 - It is VERY difficult to assess flushness as we are not permitted to touch the sensitive front face of the sensors! 0.001" shim stock was used and “dragged” across the surface until “catching” was felt to assess protruding regions.
 - We discovered three Vateil sensors with noticeable differences from the rest:
 - S/N 2803 arrived with discoloration and pitting on the surface. It almost appeared used...
 - S/N 3478 arrived with discoloration and shrink tubing at the wire/housing interface. The wire is noticeably weak at the base of the housing.
 - S/N 2858 appears to have been sent with a coating applied, which if true decreases the response time from 17 microseconds to 300 microseconds.
 - Vateil provided the following responses to our photos of the sensors:
 - When SN 2803 & 3478 were manufactured, the gages were coated (This is the usual procedure). Since the order was for uncoated, the coating was removed from the sensor face. The black coating did not totally remove from the epoxy and housing surfaces (The coating was exposed to calibration heat before removal). What appears to be shown in the pictures is some coating residue that could not be removed. To remove the residue would require a more aggressive cleaning (this could increase the chance of damage to the sensor). If there is concern, the

gage could be returned and more effort would be given to remove the coating residue.

- SN 3478: The shrink tube is not part of the wire strain relief. (Only SN 3478 has shrink tube). The method of wire strain relief is a mechanical lock inside the housing. The shrink tube could be removed (not sure why it was installed on SN 3478). If there is concern, the gage could be returned to Vatell for verification.
- SN 2858. The gage is not coated. This is verified by the light colored epoxy portion of the sensor face. Sometimes there is a slight discoloration on the face of the sensor. (Appears to be caused by slight variation in the manufacturing process). The variation is accounted for in the calibration process. Usually, the sensor face is coated and any difference in the sensor face color is not seen. The calibration record was reviewed and there was not a problem with the calibration.
- As one spare Vatell was ordered, and one of the gages is purportedly without coating as requested, only one of the affected sensors will need to be used. APL will choose either SN 2803 or 3478 to install. The gage will be placed in the first off-centerline location on the starboard side, as this is a symmetry measurement. In addition any roughness from the pitted epoxy would not affect any portion of the experiment. Also the boundary layer would be quite thick here.
- It does appear that the uncoated sensors ordered for BOLT might differ from those that flew on HIFIRE 5b, which may have been coated.
 - This was just discovered on 11 September
 - Brad ordered uncoated because it was listed in the HF5b instrumentation spreadsheet.
 - Brad confirmed with Vatell that the coating is mainly important for radiative heat transfer (which isn't a driver for us), to get the emissivity closer to 1, also since the calibration is applied with a heat lamp it does help the accuracy.
 - The coating does not affect survivability or max use temperatures of the sensors.
 - But the coating would have reduced response time (300 microseconds vs 17 microseconds) so with our uncoated sensors we should have much better ability to detect the transient features we're after.
 - The coated vs. uncoated is another of many small details to keep track of, and it seems we may have not been consistent with HF5b in this regard, but it should not affect survivability.

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- PCB-132 Sensors
 - While preceding instruments were getting installed, we were getting back up to speed with the GoHypersonic established procedure for installing the PCB sensor heat sinks.
 - Ordered Momentive RTV-60 which was the recommended RTV for providing isolation between the heat sink and aeroshell. We could only find this from RS Hughes with prompt delivery.
 - Dry fitting of the PCB heat sinks is occurring 12-13 September, so that each sensor can be properly shimmed. A 0.020" nominal shim was provided for in the GHI design. For the PCB locations on BOLT 0.020" was also used per design, since appropriate shim margins were available and built into the GHI design. GHI provided shims of 0.005" and 0.003" to stock and use.
 - Following dry fitting, the RTV will be applied by the APL Composites Laboratory who has the appropriate ventilation and safety equipment and has experience with this specific adhesive. That installation is scheduled for Monday 16 September, which gives us a couple days for final checks and correction of any issues we find with the sensors as installed.
 - Isolator
 - Isolator Medtherm installs began 11 September
 - Joint TC's
 - Completed layout and mapping of joint TC's. We are awaiting a specific person to do these installs for us.
 - Internal TC's
 - 6 spare channels on the Flight Geometry will be used for internal temperatures (4 on secondary side, 2 on primary side)
 - Plan to attach paste-on TC's to upstream and downstream boards to compare board temperatures.
 - Wiring and Integration
 - Received from Dave Adamczak supplied needed for final wiring:
 - All ribbon cables from boards to TSM
 - Wires for accelerometer in TSM/PSM but that use a sensor board in the Flight Geometry
 - Wires for PCB data system power and outputs
 - Although the secondary side wiring was completed on 8/16, the wires were not bonded and staked until Brad and Dennis could test the instrumentation.
 - All wires were correctly routed to their proper board locations.
 - All 12 Kulites (8 PLBW and 4 PMBW) appeared operational, within the proper range, and in the correct location on the secondary assembly. The Kulites were

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- tested locally with suction applied via a hand pump purchased on Amazon (Mityvac MITMV8500 Silverline Elite Automotive Vacuum Pump Kit)
- Medtherms were tested locally with a heat gun applied for ~1 second on the surface.
 - TLBW 265/266 front and back face channels were responding with very similar output, which was an odd finding. Upon removal of the pins from the Molex connector and re-insertion, the gage responded normally.
 - Noted some drifting in the TLBW134 channel... something to watch.
 - TLBW 123/124 neither junction responded. The connector was pulled and wires tested for continuity. The junctions appeared fine on both sets of leads. A new connector was applied but the gages are still not responding. This sensor is likely inoperational.
 - TLBW135 was completely broken on install (as noted in the past).
 - Dennis correctly found that TLBW 136 was hooked up as a back-face only instead of a front-face only – very easy to do since Medtherm colors the negative leads both red! We verified by loading the connector into a dual-channel location on the board and observing the response rate of both channels. The connector pins were swapped and re-tested.
 - All remaining front-face only sensors were also re-tested again to verify that the response was correct.
 - The remaining 20 Medtherms all responded correctly to the heat gun.
 - After correcting TLBW136 and TLBW265/266 we assess that 22 of 24 Medtherms are working at this stage
- Secondary side Medtherm isolation vs. noise testing
 - The secondary side Medtherm electrical isolation from the aeroshell was previously recorded for a set of 19 sensors
 - Those 19 sensors were connected to the GUI and the envelope of noise in bits was recorded for each location, while the sensors were at equilibrated room temperature.
 - Observed noise varied between 3 to 8 vertical bits, but no effect of number of bits of noise was seen with respect to the measured electrical isolation. In addition, all sensors appeared to functionally respond to heating inputs.
 - These data have been recorded in a spreadsheet for post-flight analysis.
 - Secondary Side Potting and Staking
 - Arathane 5753 polyurethane casting compound was recommended by the APL electronics technicians for securing wires to the connectors it is rigid yet flexible to vibration and withstands both cold and elevated temperatures. They typically use it for space applications.

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- A test application was made to show the bonding of the wires around the entry point to the Molex connector. The Molex connectors do not permit potting around the pins, so they can remain somewhat flexible, so the potting was only applied to the exterior to keep the wires from pulling out of the pins.
 - The 5753 was applied to the connectors in-situ as the parts had already been tested with the connectors installed and verified operable.
 - 5753 was also used to secure the sleeving to the connector. A flexible shrink wrap was demoed, but it would require pulling the connectors to apply it, and instead we decided just to use the 5753 to secure the sleeving.
 - 5753 was also used to bond portions of the sleeving bundles to the aeroshell.
 - The bundles were also tied with cable lacing “Gudebrod 21DPTH”
 - Lessons learned from wiring the secondary side to be applied to the primary side, hopefully speeding the process!
 - Sleeving used on secondary side was RS Pro Acrylic Fibreglass Cable Sleeve 0.16(4mm) Dia 16' 5"(5m) Sleeve Length Red. It comes in only 2mm and 4mm. We found that the 2mm didn't fit over the -11586 Medtherm wires easily, and the 4mm was used but was rather bulky.
 - Given the much increased amount of instrumentation on the primary side, ordered Insultherm TruFit from WireCare.com which actually has a very high temperature rating compared to the RS Pro
 - P/N FGLG.09RD, INSULTHERM® TRU-FIT - 9 AWG, RED 100FT SPOOL, QTY (2)
 - P/N FGLG.10RD, INSULTHERM® TRU-FIT - 10 AWG, RED 100FT SPOOL, QTY (2)
 - Decided format for drawings, spreadsheets, etc. that specify mapping of wires to boards
 - Decided potting and staking procedures and materials
 - Publicity
 - Aerospace America article follow on interview
 - Provided photos to Aerospace America for the October article (previously cleared only!)
 - APL is planning a new “Tech Splash” video documenting the BOLT manufacturing and instrumentation activities.
 - The video crew will be at the 9/27 onsite meeting to interview Ivett and others on the team about BOLT
 - Inspection Status
 - 1. CMM measurements of individual joint planes and alignment features (completed on Nosetip and frustum, needs to be completed on isolator)

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- COMPLETED all individual joint planes with recent Isolator fore/aft measurements
 - Brad reviewed all data to ensure that we have all we need to determine alignment and potential variations, although much of this analysis will be done later using these data
 - Some numbers on the nosetip/isolator joint:
 - Alignment clocking tab clearances between the nosetip and the isolator were measured with a total clearance of 0.0001" for one tab and 0.0002" for the second tab
 - The 5/16" dowel pin slip fit hole measured 0.3132". Assuming standard dowel pin diameter minimum of 0.3126" the maximum total play would be 0.0006" in the spanwise direction.
 - Above gives some idea of the worst-case variations in at least the upstream joint
 - 2. CMM measurements of final assembly
 - May need to do this when it returns from AFRL for testing at APL, or after testing... due to schedule
 - 3. Photogrammetry of final assembly with shims
 - May need to do this when it returns from AFRL for testing at APL, or after testing... due to schedule
 - 4. Mold measurements of joint steps
 - Per conversation with Brandon Chynoweth, these to be handled by Purdue, with first round when payload is at RQ
 - 5. Profilometer (RQ asset, will explore doing something in situ during payload assembly if risk of surface finish damage is deemed acceptable)
 - CFD/Stability
 - Per request provided NASA Langley's Chau-Lyan Chang with BOLT LASTRAC mean flows from APL solutions so he can do more LASTRAC runs. Requested that he explore nonlinear interaction between the calculated second mode and stationary crossflow modes.
 - Assembly and Crate
 - GHI sent assembly rig hardware to APL
 - APL still plans to build wooden crate prior to shipping to AFRL/RQ

9/12/2019 through 10/11/2019

- Upcoming dates/milestones:
 - October 2019
 - 30 October (?): Complete wiring and packaging of primary assembly
 - November 2019

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- 31 October to 2 November (?): Final integration @ APL
 - Inspection @ APL (photos, joint photos)
 - Week of 4 November (?): APL delivers fully instrumented Flight Geometry to AFRL/RQ
 - November-January 2019 – Environmental Testing @ JHU/APL ETF facilities
 - Entry 1 (trending towards missing this)
 - 13-15 November: Vibration
 - 18-22 November: Thermal (round the clock)
 - 25-16 November: Vacuum
 - Entry 2 / Entry 1 Alternate:
 - 4-6 December: Vibration
 - 9-13 December: Thermal (round the clock)
 - 16-17 December: Vacuum
 - Entry 2 Alternate:
 - TBD – inquiring with facility schedule for January openings
 - 1 March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @ Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - Fabrication
 - Performed helicoil repair on two main surface to gutter threaded holes in situ in the electronics lab. The helicoils were added successfully. The two threads had been damaged during initial fitup activities and were not holding the required torque.
 - 3D printed plastic template representing the ballast instrumentation pathways, for assistance in routing wires underneath the portion of the primary side where the ballast will be installed.
 - Fairings
 - Fairing first build started on 27 September
 - An initial test piece was built in a single build, to test out the process, assess amount of powder required, etc.
 - Fairing final build completed on 10 October
 - The flight parts were built two at a time
 - Fairings will be sent to EDM group to be removed from the build plate, and some conventional machining will be done on the through holes, etc.
 - Instrumentation Installation
 - Completed installation of the Medtherms into the Stainless Steel isolator part
 - Completed installation of the PCB heat sinks and PCB132 sensors into the flight hardware.

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- For all the heat sinks, the baseline 0.020" shim stock combination was used and the sensors were deemed sufficiently flush such that no alterations to the shims were required.
 - Completed installation of the joint "snakebite" thermocouples into the aluminum parts, and later into the TZM tip and isolator
 - The practice installations on the test TZM tip had no issues so the decision was made to install the sensors on the flight tip
 - The stainless steel snakebite holes proved difficult to deburr and clean, and the small drill bit used for cleaning the holes to permit entry of the TC wire broke several times. At three locations, new holes were drilled next to the ones with the broken drill bits to enable all TC locations to be installed successfully.
 - Additional paste-on internal temperature TC's were added to the aluminum frustum.
 - On the primary side, two locations were available. One past-on TC was added to the PCB #2 heat sink (S/N 8615) which was the forward most outboard PCB to gather temperature data on the heat sink itself. A second TC was added to the inner mold line of the aeroshell forward of the PCB. These two measurements may be useful to evaluate the performance of the PCB heat sinks.
 - On the secondary side, two were placed on sensor boards and two were placed on the inside of the aluminum near the isolator interface
 - Broken:
 - Medtherm TLBW 135 (S/N 139) secondary side, broken on installation
 - Medtherm TLBW 123/124 (S/N 14) secondary side, not responding during secondary side testing
 - Medtherm TLBW97/98 (S/N 130) during installation of sidewall
 - Open sensor issues:
 - TLBW16 is noisy, will be checking connector and pins. We do have an extra sensor if we decide to swap this sensor, however it is in an upstream spot on the primary side and we risk the second install not being as flush.
 - Wiring and Integration
 - Began planning of the ribbon cable strategy, for the ribbon cables exiting the sensor boards. This resulted in a recommendation for all stacks to face the same direction. Some sort of clamping mechanisms may be explored to secure the ribbon cables to the top board standoffs.
 - Two boards were flipped upside down in order to improve the flow of ribbon cables and avoid them interfering with the connectors on each stack.
 - Added high-temperature sleeving to the PCB132 cables.
 - Decided to add to thermally protect the PCB132 supplied cable (from the sensor to the 10/32 coax connector) and the second cable (10/32 coax to SMA). The latter's drawing from Bracke specifies a max operating temperature of +80

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- degC. The former is an FEP cable that comes with the sensor, but didn't seem to have any temperature limits written specific to the wire.
- Ordered larger diameter Insultherm(R) Tru-Fit sleeving to put over the PCB132 cables
 - Installed PCB high speed DAQ box in Flight Geometry, but are exploring moving the PCB box to the PSM to provide improved access to the system if later updates or debugging is required.
 - Dave confirmed the worst case CG shift is about 0.02 calibers, and the effect on dynamic stability parameters would be negligible (moving the box to the PSM may let us place it more centrally located which actually might improve mass properties)
 - Would need to order longer coaxial cables to go from the 12" PCB132 cables to the PSM location
 - Discovered that the Vatec sensors came with widely varying calibrations, which will result in 4 of the sensors having $\frac{1}{4}$ of the vertical resolution of that expected due to preset gains
 - The aim point for saturation set in the boards was 0.0405 V, assuming a calibration of 27.0 $\mu\text{V}/\text{kW}/\text{m}^2$ from historical sensors on HIFIRE-5b.
 - This was an aim point of 1,500 kW/m^2 , which we set high hoping to obtain turbulent heat flux measurements. The resolution of laminar heat streaks, which we are also interested in, was deemed sufficient due to the high resolution provided by the 24-bit A/D converters
 - Looking at the BOLT HFM-7 calibration sheets these are the values for max and min:
 - Highest = S/N 3353 at 27.7 $\mu\text{V}/\text{kW}/\text{m}^2$. This one is close to the aim point, maxing out at 1462 kW/m^2 .
 - Lowest = S/N 3356 at 6.7 $\mu\text{V}/\text{kW}/\text{m}^2$. This one is only 25% of the aim point (we're reducing the resolution by a factor of 4), maxing out at 6,000 kW/m^2
 - The gains could have been adjusted by APL staff by swapping out some resistors, but would require Dave Adamczak to fly to APL to recalibrate the flight computers
 - Decided to leave the board gains as is for these channels, since the 24-bit A/D converters provide sufficient resolution and the number of sensors affected in a significant way were low (worst case 2 bits of resolution were sacrificed). Schedule was also a concern as we want to integrate the boards ASAP.
 - Started Primary board checkouts
 - Initial 5 of 18 boards
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- 2A, 6A, 6B, 10A, 12B
 - 70 total channels
 - Only 1 issue discovered
 - 30 Medtherms (60 total channels) all operating and in proper locations
 - TLBW 95/96 hooked up in reverse, noted but will leave as is
 - Freeze spraying q-tip method working well (thanks Aaron!)
 - 2 Snakebite joint TC's responded positively to heat gun
 - 4/4 PMBW sensors responding
 - 3 of 4 PLBW sensors working, 4th is noisy (5 psia sensor) and will be debugged
 - Publicity
 - High Mach article
 - PDF:
 - <https://media.defense.gov/2019/Sep/13/2002182544/-1/-1/1/HIGH%20MACH%20-%20SEPTEMBER%2016,%202019.PDF>
 - Web link:
 - <https://www.arnold.af.mil/News/Article-Display/Article/1961854/tunnel-9-personnel-provides-guidance-for-hypersonic-experiment/>
 - Aerospace America Magazine
 - PDF:
 - Web link:
 - <https://aerospaceamerica.aiaa.org/departments/decoding-the-boundary-layer-at-hypersonic-speeds/>
 - Assembly and Crate
 - Working on design of polycarbonate “negative” inner piece to interface with the GHI handling frame. Working to design protective features into the handling apparatus particularly for the nosetip.
 - Beginning design of wood crate to hold the Flight Geometry, TSM, and PSM
 - Medtherm offered opportunity to cancel remaining 25 undelivered sensors, after discussions with Ivett and Rodney decided to do so. Amended PO was processed and \$24K funding was decommitted and provided back to the grant budget.

10/12/2019 through 11/11/2019

- Upcoming dates/milestones:
 - December-February 2019 – Environmental Testing @ JHU/APL ETF facilities
 - Entry 1:
 - 4-6 December: Vibration
 - 9-13 December: Thermal (round the clock)
 - 16-17 December: Vacuum

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- Entry 2 (as scheduled):
 - 5-7 February 2020: Vibration
 - 10-14 February 2020: Thermal (round the clock)
 - 17-18 February 2020 November: Vacuum
 - March 2020 – Deadline for DLR to receive payload
 - April 2020 – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 – DLR environmental testing @Ottobrunn (Airbus)
 - May 2020 – Launch Campaign @ Esrange Sweden
 - NOTE: These status bullets reflect the final assembly and integration at APL of the Flight Geometry prior to shipping to AFRL/RQ on 11/11/2019
 - Instrumentation
 - Completed final electrical integration and testing activities at APL
 - PLBW16 was not responding 10/15/19. We believe the temperature compensator got pinched at some point with the ballast. We removed sensor S/N 8195-1-338 and replaced it with S/N 8162-9-90 (spare 5 psia sensor).
 - The Vatell gauges proved to be very troublesome with the Molex connectors.
 - Wires would be cut, soldered, and crimped, and then lose their connection along the way
 - APL performed a systematic check of the continuity of the Vatell wires and determined that the failure was occurring during the crimping stage
 - With the exception of board 5B (first Vatell board installed), the remaining boards were installed with just soldering and no crimping into the Molex pins. This seemed to have better success. HT1 and HT2 on board 5A were reading good with the existing crimps and were left as-is. HT3 was repaired with the new style connection and began working. HT4 appears dead.
 - Four of the 16 temperature channels on the Vateils are broken, and were unable to be fixed
 - Shipped to AFRL/RQ with these known failures:
 - We believe we were operating with all 48 Kulites responding normally.
 - Out of 268 thermocouple channels, only TLBW97/98, TLBW123/124, TLBW135, and TLBW145 appear to be broken for a total of 7 channels down.
 - We did unfortunately lose the heat flux output measurement on 1 of 16 Vateils, and for 3 of the remaining 15 Vateils the temperature compensation circuit is not working.
 - Completed design and fabrication of handling frame interface
 - Polycarbonate negative with ceramic felt is used to hold the front end of the Flight Geometry
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- Tom Wolf ran load calculations and determined that placing the polycarbonate negative on the aluminum side, rather than the stainless steel side, is best due to bold loads and moments
 - The polycarbonate negative includes a large o-ring intended to absorb some vibrational loads encountered during shipping
 - A sheet metal protective cover was created to cover the nosetip assembly, preventing accidental damage during handling
 - Machined additional tungsten parts to recover the ballast weight to 22.594 kg
 - Finished building the wood crate for shipping
 - Some modifications and foam inserts had to be added the day of shipping
 - Logo completed
 - Masses of components gathered
 - BALLAST: measured 19.90 kg (nominal 22.4 kg) (we got a second measurement on the shop scale that was close to this one...19.882kg). This was later recovered to nominal weight with additional tungsten.
 - Nosetip assembly (tip + isolator + wires): measured 7.75 kg (nominal 7.66 kg)
 - Main surface test piece (only aluminum): meas. 12.80 kg (nominal 12.895 kg)
 - Gutter test piece (only aluminum): meas. 3.65 kg (nominal 3.69 kg)
 - Secondary assembly (main surf + gutter + 4 boards and wires, PCB box removed, with plastic braces attached): 19.15 kg (the metal pieces should add up to 12.80+3.65=16.45 kg which means the plastic braces and boards added ~2.7kg ?)
 - Measured the PCB box, bolts, and cables and the total weight was 1.40 kg which is much less than the 3.0 kg estimate. The CG shift is thus 0.009 calibers not 0.02 calibers, considering just the move of the PCB box alone. I've pulled the PCB box and we can ship it back to AFRL/RQ anytime.
 - Testing of instruments
 - Tested each board incrementally as the layers were built
 - Experienced issues with the flight computer connector, which had to be repaired on one occasion
 - On the last day, began to experience issues with the test flight computer. Switching to the second node on the unit allowed testing to be completed, but the first node is likely faulty.
 - Needed to remake all ribbon cable connectors to have them turn the right way coming out of the Flight Geometry
 - Completed tip inspection of primary quadrant leading edge contour
 - Performed final assembly on 11/9/2019
 - Overall it went very well
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- Re-checked all ribbon cables after assembly, and determined that no instruments were damaged during the assembly
 - Torqued and applied Loctite to nosetip/isolator bolt, frustum/isolator bolts, frustum bolts
 - Only issue during assembly was a nick in the secondary side leading edge, Quadrant D, which was subsequently repaired the next day. The nick was on the gutter side but the repair did leave a slight discoloration of the surface finish.
 - Shipped out to AFRL/RQ on 11/11/2019
 - Via APL courier

11/12/2019 through 2/14/2020

- Upcoming dates/milestones (note that DLR is yet to commit to the May 2020 date for the flight campaign as it may need to slip somewhat, thus the uncertainty in this schedule):
 - March 2020 (??) – Deadline for DLR to receive payload
 - April 2020 (??) – DLR bench testing @ Oberpfaffenhofen
 - April-May 2020 (??) – DLR environmental testing @Ottostrun (Airbus)
 - May 2020 (??) – Launch Campaign @ Esrange Sweden
- **Catch-up update covering activities between November 2019 delivery of Flight Geometry to AFRL/RQ and February 2020**
- (November 2019) Flight Geometry delivered from APL to AFRL/RQ
- (December 2019) Environmental testing at APL Environmental Test Facilities (ETF)
 - Thermal testing completed 12/9-12/12
 - Altitude testing completed 12/12
 - Payload shipped back to AFRL/RQ via APL courier on 1/7, arrived 1/8
 - Modified handling frame for safer lifting
 - Corrected improper diameter of shipping crate for PSM
- Issues with PCB132 high speed data acquisition system
 - Experienced communications failure of the PCB132 high speed DAQ boxes unrelated to environmental testing
 - Dave was unable to debug while at APL for environmental testing
 - Issue was discovered, described via Dave Adamczak email on 2/13/2020:
 - GHI thought they had fixed the problem with the system dying from the JHU testing. Well we were able to kill 3-4 more of the systems during testing. We were able to do this before installing in the payload and in the payload. After a bit more trouble shooting we have identified the problem. GHI had designed the power input to pass thru a resistor and a capacitor to provide for both short circuit protection and some EMI filtering.
 - We discovered that when the power is turned on to the HS DAQ in the payload it is near instantaneous from 0 to 28V (few microseconds). This very sharp turn

on was causing a very quick buildup of current in the resistor due to the capacitor in the circuit and burning out the resistor. When the unit were tested before, they were run off a power supply and most power supplies have a soft turn for voltage rising in a short time (100msec) and could not reproduce this problem. So when we did hard switching with a power supply we were able to kill the resistors and the devices duplicating the problem.

- So for temporary testing we removed the resistors from the power input and this caused the units to function as designed. We were able to talk to the data system on both CAN and RS-232 networks. We were also able to feed a sine wave in at 200_Khz and record data and output TM processed data.
- So GHI is going to modify the devices to remove the capacitors and keep the resistors. This could remove some EMI protection but we are already protecting the main power supply so should not be an issue. We will keep the resistors to keep short circuit protection as we don't want to kill entire payload is we get a short. They may also try to find a higher power resistor that could work and keep both but time may preclude this.
- GHI completed design upgrade to send some information of PCB132 high speed DAQ into telemetry
- TriModels modifying subscale model for better controlled joint steps for Purdue experiments
- AFRL working on BOLT Operation Security (OpSEC) plan for overseas activities
- Joint Step Measurements
 - Purdue completed molds of joint steps at AFRL in November 2019 and analysis of the steps is ongoing
 - Brad Wheaton working with Chris Yam and Brandon Chynoweth to quantify uncertainties in the mold analysis process. Chris has made great progress collecting measurements on the molds and they appear to be the best set of measurements thus far on the steps.
 - APL shipped coated test nosetip to Purdue, along with Ultramet inspection report, for further development of mold analysis techniques for distributed roughness
 - Brad Wheaton and Scott Berry visited AFRL in January 2020 and completed a series of photographs as well as notes on feeler gauge measurements. Also borrowed Matt Borg's profilometer to take several surface finish readings on the experiment surfaces.
 - Successes:
 - Recorded feel with feeler gauges when able (easiest on flatter portions, difficult on leading edges)
 - Feeler gauges bounded the secondary experiment leading edge steps well

- Depth micrometer on flatter portions produced nicely repeatable results
 - Profilometer obtained surface finish average roughness (Ra) on tip, isolator, and frustum, but only on main flat surface
 - 16-20 microinch frustum, 20-30 microinch isolator, higher than expected on tip (20-50 microinch)
- Challenges
 - Repeat of May 2019 photos but with iPhone macro lens, but optical distortion effects may preclude quantitative measurements. No access to photograph joints from farther downstream with previous method.
 - Profilometer attempted on steps but mean level was removed from signal (software filter or perhaps the stylus reference datum on the skid)
 - Quantitative measurements of peak step on leading edges remains elusive due to curvature!
- Identified skidless profilometer system that may be better able to measure steps. Purdue has ordered one for their Mach 8 tunnel development and will test the unit to advise on its performance.
- BOLT Special Sessions held at AIAA SciTech 2020
- Journal of Spacecraft and Rockets
 - Authors need to submit their articles to JSR as soon as possible!
 - APL paper is still in review with USAF
- BOLT Transition Prediction Challenge
 - Announced by Roger Kimmel at AIAA SciTech 2020
 - Brad completed data package and is logging distribution of the data package to various groups
 - APL also completed extracting Re_theta/M_e, LORN, etc. from existing CFD solutions
- BOLT Gear
 - Brad is working on setting up an ordering site for team gear
 - Holdup has been that logo is full color, and screen printing or embroidered patches would require some simplifications to the logo
 - Path forward could be “direct to print” methods for t-shirts

2/15/2020 through 3/27/2020

- Upcoming dates/milestones (note that DLR is yet to commit to the May 2020 date for the flight campaign as it may need to slip somewhat, thus the uncertainty in this schedule):
 - TBD due to covid-19 – Deadline for DLR to receive payload
 - TBD due to covid-19 – DLR bench testing @ Oberpfaffenhofen
 - TBD due to covid-19 – DLR environmental testing @Ottobrunn (Airbus)

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- TBD due to covid-19 – Launch Campaign @ Esrange Sweden
 - **Catch-up update covering activities in February and March 2020**
 - **COVID-19 CAUSES DELAY IN FLIGHT CAMPAIGN**
 - Original flight campaign postponed indefinitely... working through DLR to secure a new slot at Esrange (aiming for late August 2020)
 - Constraints on rescheduling:
 - Schedule far enough in advance to enable reasonable chance of covid-19 situation to improve
 - Availability of ample daylight for flexible payload recovery
 - September: 12-14 hours
 - October: 7-9 hours and decreasing quickly
 - Snow cover interference to payload recovery operations
 - Can be as early as October.
 - Per DLR this is most critical factor in recovery.
 - Predominant wind direction for simultaneous balloon operations (after October bad!)
 - Moose hunting season in September (range typically closed all month)
 - Shelf life of Flight Geometry electronics and instrumentation (don't want it to sit another winter)
 - **DLR will explore possibility of late August 2020 window.**
 - Germany testing/integration activities would probably need to begin no later than late June or early July.
 - If covid-19 related travel restrictions ease before then, we will try to get an early start on testing.
 - US-based Flight Geometry payload progress
 - PCB132 high speed DAQ status
 - Modified high speed DAQ system has been re-installed into payload and power cycled ~10times with no failures.
 - HS DAQ was also tested with a simulated sensor input (400khz sine signal) and output was recorded in telemetry with no issues.
 - Telemetry channel test system
 - Put together a 3 channel telemetry test system to take to DLR pre-launch for telemetry integration with DLR transmitter system.
 - This simulates the 3 telemetry streams from BoLT with the same flight hardware to check the telemetry transmission and reception.
 - We will also be able to test the real-time telemetry feed that will go into the control room for viewing. This will save time during the launch activities to have this set up beforehand.

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- Complete countdown and sequencing completed 3/4/2020
 - Completed complete countdown and flight sequence. So far all systems are working as planned and all mission event are triggering as planned. Done multiple times.
 - For this test AFRL/RQ does the following:
 - start the countdown from T -2min and then activate the payload systems.
 - At T -1min we set the final clock on the payload.
 - The payload then waits for the launch signal to start the internal clock.
 - At T=0 we trigger the launch signal (1 of several things are checked, umbilical pull is primary, Loss of communication is next, then a time as last resort.) I pull the umbilical's manually to trigger.
 - Payload then starts internal clock relative to T=0.
 - T=17sec we trigger HSDAQ ascent window. (HS DAQ takes data, saves data, the outputs data to TM, each phase takes 17-20sec)
 - T=490sec we trigger HSDAQ (HS DAQ takes data, saves data etc, this time only for 8secs of data collection)
 - T=650 sec (~100sec after end of mission) we turn off the payload to safe it (may be moot point as payload will have crashed into ground already and probably break up)
 - Now the only issue remaining is the time (T=490sec) we trigger the 2nd HSDAQ data window at. I was looking at the trajectory dispersion from the past and the time window goes from:
 - 1sigma 498.9 to 515.7 sec
 - 2sigma 490.5 to 524.1 sec
 - 3sigma 456.9 to 557.7 sec
 - I we trigger the HSDAQ on reentry too early or late we can totally miss the relevant Reynolds number window.
 - So AFRL/RQ is going to use a trigger based on the GPS altitude. It looks like triggering at just below 35km will get the correct Re range. This will be added this to the flight code. If GPS is out then time will still be a trigger.
 - Dave Adamczak was able to travel to Germany JUST before the European travel ban to complete critical testing of the telemetry interface with the DLR systems. Dave's summary of the trip is below:
 - 1. We interfaced the DLR timing signal to our flight computers thru the telemetry cable. We were able to read the DLR flags correctly. This will allow us to help sync the flight clocks and also the liftoff timing event.
 - 2. Using the test system I brought we hooked up the TM output from the flight computers to the DLR transmitters successfully. We were able to transmit 2 channels thru the TM setup at DLR (they only had a 2 channel receiver to use in office). We output a fake TM stream which caused some issue on reception. Since the TM stream was not real the bits did not change much in

the TM words so signal was not that good. We also tried to simulate TM dropouts and this caused loss of the signal. We then decided to rewire the computer system I brought to be exactly like the flight system. I brought enough hardware to setup one TM channel this way.

- 3. Using the rewired computer system we were able to look at a more representative flight TM signal. This had a lot more bits changing the TM stream as we will in flight. This signal was improved from the test in 2 by quite a bit. We then were able to test dropping out some data from the TM stream by turning off a single flight computer. This worked better than in test 2 previously but was not an ideal signal. We then looked at channel interference and hooked up a 2nd TM stream that DLR had available. this allowed us to test if the channel spacing for the S band frequencies were ok. We were able to demonstrate that channel spacing was adequate and did not cause loss of signal. while the TM reception was adequate in this set of testing and could be used in flight the DLR still recommends adding IRIG Randomization to the TM outputs. They were able to demonstrate the benefits of this on a test system they had. We left for night and then came back Thursday for more testing. Sebastian Weiss from DLR must have had a lot of time on his hands so he built a randomizer circuit before he left for the night.
- 4. With the randomizer circuit that DLR built we wired this into the DSP TM output for 1 channel. After some debugging of the wires we were able to achieve randomized TM output. We were then able to lock onto this signal with both the DLR receivers and the TM station that I brought. DLR was able to demonstrate the randomized signal was superior to a non-randomized signal. This improves the TM signal to noise, reduces required bandwidth (in frequency spectrum) and it also allows for a dropout of a flight computer. If we would lose one flight computer the TM would still be receivable where without randomization we would lose TM lock. If we lost TM lock we may lose it for good. This eliminates that issue.
- 5. We then conducted more TM testing. We were able to test the effects of range on the TM signal by attenuating the signal out of the transmitter. We were able to attenuate the signal by 12db before loss of signal. This is comparable to other DLR systems. We also demonstrated loss of a single flight computer and no loss of signal was seen. So the randomizer makes the system more robust to single system failures.
- 6. DLR shared with us the randomizer circuit and I am going to design a board to add this into our system for all three TM channels. This is a very simple circuit and I should be able to get this made fairly quickly. We will then mount

this on a stack of flight computers and be able to wire into the TM very easily. We will then be able to ground testing this in the payload testing at DLR.

- 7. We also discussed the range interfaces and DLR shared displayed some photos of the setup for the launch just conducted. We discussed how the setup would interface to our GSE box at the launcher. One issue that came up is the box is totally exposed to the environment as there is no enclosure on the tower. Our GSE is in a pelican case but we will need to modify to have some sort of pass thru for cabling that has some way to be closed off from outside to protect from weather and the rocket exhaust during launch. We discussed the data lines for the real-time telemetry and what we can get receive. They will be able to send us both TM stations and then we can switch to the best source if needed. We will have to but a coax switch to do this. (need a 2x 3 input switch, I will buy or find one). We can then setup our TM decom station in the block house to take in the TM. We can then distribute this for real-time viewing of some channels of TM. We can setup a few computers at different locations to display plots real-time. This is another item I have not had much time to work on but if we delay can do a better job of this.
 - 8. We also talked about how we will do the payload control pre-launch and they have the necessary serial interfaces to tie in our systems. We will bring some as back-up (have 6 units to use). We also need a single Ethernet line to the block house for checking the high speed DAQ startup.
 - 9. We also discussed the data files recorded during them mission and they can export in two formats. One is a wideband company format and the other is an IRIG Chapter 10 format. We have used the chapter 10 format before so will ask for that. They will record both Tm stations and then be able to export in both formats. We can get the data on an external hard disk to take home. We can then process into our TM station to build the final data files needed for post processing.
- BOLT mission patch t-shirts
 - Order deadline extended to April 30th
 - Link to order here:
 - <https://www.customink.com/g/puj0-00c5-haxy>
 - APL collecting rocket decal logos
 - APL grant and funding situation
 - APL continues in low-spend mode to wait out delays
 - Overall funding available is sufficient to wait out low to moderate delays through September 2020
 - Grant received no cost extension through 31 August 2020 (thanks AFOSR!)
 - Second grant awarded 3/11/2020 for APL BOLT2 support and to support post-flight data analysis (thanks AFOSR!)

3/28/2020 through 5/29/2020

- Upcoming dates/milestones (based on progression toward August 2020 flight campaign):
 - 20 JUNE: Target date to ship payload to Germany
 - NLT 28 JUNE: Payload and associated test equipment arrive @ DLR MORABA
 - 29 JUNE through 04 JULY: DLR MORABA performs bench testing activities, no US team presence
 - 06 JULY: AFRL/RQH, JHU/APL BOLT team travel to Munich, Germany, arriving 07 JULY
 - 08 JULY through 11 JULY: Entire BOLT team, AFRL, JHU/APL and DLR, work together to un-pack; build-up; check-out; and integrate the BOLT payload with the DLR inner-stage and ACS
 - 13 JULY through 18 JULY: Entire BOLT team conduct functional and systems operation testing at DLR MORABA Oberpfaffenhofen
 - 20 JULY through 24 JULY: Integrated BOLT team conduct certification testing at Airbus Defence and Space near Ottobrunn, Germany
 - 25 JULY: US BOLT Team return travel from Munich, Germany back to US via Washington Dulles (IAD) airport
 - 10 AUGUST to 31 AUGUST: Flight campaign in Esrange, Sweden
- **Catch-up update covering activities in April and May 2020**
- **Flight Campaign Progressing towards August 2020,**
 - **With significant uncertainty, while monitoring:**
 - Travel limitations (quarantines, employer approvals, development of safe procedures, etc.)
 - Hardware work given the reduced staffing and social distancing at the labs at AFRL and DLR
 - If August 2020 flight campaign occurs, it will be with a skeleton crew to ensure minimal risk and social distancing safety for all involved
- Purdue to make additional joint step molds at AFRL/RQ ca. early June, with NASA Langley potentially to analyze
- Journal of Spacecraft and Rockets Special Issue
 - Most papers submitted, many in revision stage
 - Please finish papers and revisions ASAP!
 - Brad sent out a list of cross-citations, here is the official list of papers:
 - Ivett: overview paper
 - “Final Design of the Boundary Layer Transition (BOLT) Flight Experiment”
 - Bradley M. Wheaton, Dennis C. Berridge, Thomas D. Wolf, Daniel B. Araya, Ryan T. Stevens, Brian E. McGrath, Brian L. Kemp, David W. Adamczak

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- High level overview of the goals of BOLT, high level summary of pre-flight ground test and computational work and how it impacted choices in design of the flight experiment, overview of the flight research vehicle, planned mission events and trajectory mainly from an experimental perspective, flight instrumentation layout and strategies, material selection, pre-flight thermal analysis (anticipated surface temperatures in flight), mechanical design of Flight Geometry, photos of fabrication, instrumentation, and assembly
 - Manuscript ID: 2020-03-A34809
 - Secondary Side Considerations for the BOLT Flight Experiment
 - Scott A. Berry, Bradley M. Wheaton, and Brandon C. Chynoweth
 - This article is intended to provide details regarding the secondary side experiment, including details into design decisions made to finalize the hardware and instrumentation for flight.
 - Manuscript ID: 2020-02-A34778
 - Pre-Flight Ground Test Analyses of the AFOSR Boundary Layer Transition Flight Geometry
 - Heather E. Kostak, Rodney D. W. Bowersox
 - Wind tunnel experiments performed on and off the surface of the 33% scale BOLT geometry to quantify boundary layer instabilities, focusing on surface heating (IR thermography) and surface pressure measurements as well as off-body measurements (hot-wire anemometry) with comparisons to the simulations/computations (UMN/TAMU). The experimental data presented in this paper were acquired at Texas A&M University.
 - Manuscript ID: 2020-05-A34858
 - AFOSR BOLT Pre-Flight Experiments in the Boeing/AFOSR Mach 6 Quiet Tunnel
 - Gregory R. McKiernan, Brandon C. Chynoweth, Steven P. Schneider, Dennis C. Berridge, and Bradley M. Wheaton
 - Quiet flow experiments on the 0.33 scale BOLT model. Smooth wall results include the behavior of surface heat transfer at various degrees of alpha and beta and high-speed surface pressure fluctuation measurements. Additional experiments on the influence of controlled step heights are documented with some correlations for flight.
 - Manuscript ID: 2020-02-A34772
 - Numerical Simulation of Instabilities in the Boundary-Layer Transition Experiment Flowfield
 - Anthony L. Knutson, John S. Thome, Graham V. Candler

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- Forced direct numerical simulation of the 1/3 scale BoLT model at Mach 6 quiet tunnel conditions. Modal decomposition is used to extract the dominant modes which are compared to quiet tunnel experiments. The results provide a potential explanation for some of the experimental observations. In particular, our results predict vortical modes near the centerline and traveling crossflow modes near the swept leading edge.
 - Manuscript ID: <https://arc.aiaa.org/doi/10.2514/1.A34599>
 - Pre-Flight Boundary-Layer Stability Analysis of BOLT Geometry
 - Alexander J. Moyes and Helen L. Reed
 - Boundary-layer stability analysis of the flight geometry at 2 predicted flight conditions using LPSE for mechanism identification and prediction and NPSE for mechanism prediction and verification.
 - Manuscript ID: 2020-02-A34792
 - “NASA Langley Aerothermodynamic Ground Tests in Support of the (BOLT) Flight Experiment”
 - Elizabeth F. Rieken, Scott A. Berry, Michelle L. Mason, Francis A. Greene
 - Review of three wind tunnel experiments conducted by NASA Langley in the Langley 20-Inch Mach 6 Air Tunnel on subscale BOLT models. Global surface heating distributions using phosphor thermography and infrared thermography. (1) First experimental measurements of transition on the BOLT geometry. (2) Effects of distributed surface roughness along the swept leading edges. (3) Evaluation of the aeroheating environment on the fairings and transition section.
 - Manuscript ID: 2020-03-A34803
 - “Mission Overview, Launch Vehicle and Payload Support Systems for the BOLT Hypersonic Flight Experiment”
 - Marcus Hörschgen-Eggers, Rainer M. Kirchhartz, Wolfgang Jung, Kathrin Schoppmann, Josef Ettl, Markus Wittkamp
 - Overall launch vehicle and flight trajectory description, introduction of mission sequence and experiment window key parameter, presentation of the payload subsystems for despin, payload separation, flight event control, attitude control, GNSS, time synchronization and TM data transmission, separation dynamics analysis, thermal analysis of motor P/L joint
 - No manuscript ID yet...
 - **Telecon with DLR on 4/29/2020**
 - Intro/update from MORABA (Rainer, Marcus)

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- As of Monday 5/3, DLR MORABA will be able to access their facilities but only with 20% personnel on each day. Will be able to use this to start hardware work on BOLT (BOLT subsystems)
 - Applied thermal protection to manacle ring after thermal analysis
 - German government has extended worldwide travel warning now until the middle of June
 - (Rainer) would need some release on travel restrictions imposed by management ahead of July, to make August launch, but situation is uncertain
 - (Leyva) If US team cannot travel, will DLR be willing to witness arrival of payload and provide proof to satisfy AFRL security. (Rainer) Yes, don't see an issue. Could also host any Germany-based USAF personnel to provide witness if necessary.
 - (Leyva) Is November window difficult to get or is it still a possibility. (Marcus, Rainer) Issue is that DLR has from September to November SEVEN missions they are involved in. If they plan BOLT for a mission slot in November they need to be careful what they do with their personnel. Rainer would prefer to close the November option in fairness to their personnel. Also have other customer needs to balance, need to be transparent to all customers (no single mission should be reserving two slots in fairness to other customers). Having BOLT planned for August now is actually relieving their schedule somewhat.
 - (Rainer) Confirms that Esrange is definitely closed in September for Moose hunting season. He has asked the question and it is confirmed.
 - Alternate to August could be January 2021.
 - When to ship hardware if flight date is uncertain? (Dave) Problem is that the other RQ gear can't be shipped as it might be needed for other projects. (Dolvin) Agreed, we'd probably want to store the payload and gear together at WPAFB in a controlled and secure environment if long term storage needed. (Rainer) Better if US team would store payload long term, but DLR also could handle it if any issue should arise.
 - (Marcus) Esrange has plans for several balloon launches in August.
 - **Telecon with DLR on 5/13/2020**
 - (Dave) Has been able to go into AFRL. Has randomizer board working. Hardware nearly done, just needs some more software work on the triggering events. Looking at trajectory dispersions to trigger HS DAQ on reentry and still has that work to do.
 - (Marcus) Sent email prior summarizing, but basically DLR has been able to access facilities and start hardware work. Progress of last 4-1/2 days on hardware has been really good! Using working conditions allowing for spacing and distance.
 - (Wolfgang) Situation in Europe. Austria and Switzerland opening on June 15. France on JULY 15. At least one state (lower Saxony) has said 14-day quarantine is not within the law. Two other states on western border have postponed 14-day quarantine. Not sure how that counts from people coming from US.
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- (Rainer) Says the EU has recommended to keep outside borders closed until June 15.
 - (Marcus) goes through new nominal schedule:
 - DLR preps:
 - SM/CGS Integration and Test, MA+MTM Integration 07.05. to 20.05.
 - Air bearing Tests with SM/ACS (HIL) 25.05. to 12.06.
 - Preparation for complete System Tests 15.06. to 19.06.
 - Need for US based team abroad:
 - BOLT complete System Tests OP and preparation AIT 6.07. to 17.07.
 - BOLT Environmental tests OTN 20.07. to 24.07. (not confirmed yet)
 - Troubleshooting/transport preparations/Transport 27.07. to 31.07.
 - Transport to Esrange 30.07. to 09.08.
 - BOLT launch campaign 10.08. to 31.08.
 - **Telecon with DLR on 5/27/2020**
 - Update from DLR (Marcus)
 - Hans has left DLR, returned to Australia
 - Starting with air bearing tests this week (end of May)
 - Promising update on avalanche tech for payload location
 - Update from RQ (Dave)
 - Completed umbilical cable
 - Didn't make accommodations for environmental sealing in the Pelican case for the power systems, might need to think about how to protect it better since it might be exposed to the elements at launcher
 - Payload in good shape
 - Made software change for triggering system on descent, still needs to test
 - Needs to rotate payload once more to fix a bad sensor
 - Purdue will come make step measurements
 - Ground computers needed to be sent back to AFRL tech guys to get set up correctly, but some of those group are only working one days a week (needs to bring 4 computers for ground system)
 - Shipping and ITAR discussion (Ivett)
 - Reports new challenges with shipping
 - Might have to remove GPS
 - Dave reports we could take out GPS if we had to, would still have DLR's two GPS onboard, but would be a shame to remove it
 - Might need to update timing events in software later, after DLR runs latest trajectories, especially for the high speed data system
 - Travel restriction update?
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- No change from Germany side since last update. June 15 release of travel restrictions, but this is for intra-EU travel. Not sure if quarantines will be lifted. Have said they will treat every country individually.
 - No current reported infections at Esrange
 - DLR suggests accounting for 14-day quarantine
 - DLR currently in discussion with DLR “Crisis Management” group to identify any limits or restrictions for visitors, not sure they can do any earlier than 14-day quarantine
 - DLR looking into charter flight from MORABA to Kiruna, potentially allow direct flight from US to Germany, followed by direct flight to Kiruna. Minimizes contact for entire team.
 - August flight potential planning?
 - Brad to send vastly reduced attendance list

5/30/2020 through 4/27/2021

- **This update covers a large period of time where the impacts of COVID-19 resulted in significant delays to the BOLT project, including several mission delays.**
- Ultimately, the flight campaign in August 2020 was delayed due to COVID-19.
- The initial next available slot was February 2021, however due to likely future COVID-19 case rise over the winter as well as harsh environmental conditions, the BOLT team requested a slot in spring 2021 from DLR and Esrange.
- An initial campaign slot of 25 April 2021 to 15 May 2021 was requested, and was initially confirmed ca. October 2020 by DLR. However, a large rise in COVID cases ahead of the end of 2020 prompted a proactive further delay request to June 2021.
- At end of January, 2021, DLR confirmed an available slot of 10-30 June 2021 which was the latest slot they could offer. The BOLT team decided to change to the new June 2021 campaign slot.
- APL began some initial work on post-flight development tools, however largely most of the APL work was on hold during this delay period to conserve funds.

4/27/2021 through 5/15/2021

- **This update covers BOLT integration and environmental testing activities at DLR MORABA in Oberpfaffenhofen Germany and Airbus Defence and Space Ottobrunn Germany in May 2021.**
- A small team from AFRL/RQ (David Adamczak and Joshua Day) as well as APL (Brad Wheaton and Tom Wolf) traveled to the Munich Germany region to support BOLT integration and testing activities at DLR MORABA (Oberpfaffenhofen) and Airbus Defence and Space environmental test facilities (Ottobrunn)
- Payload arrived in Germany after considerable difficulties with shipping/logistics
 - Arrival date ended up being several days to a week after the USA team arrival

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- Payload arrived in Frankfurt airport morning of Saturday 1 May, was retrieved that evening by DLR and was delivered to MORABA on Sunday 2 May
 - Thanks to DLR for rescuing our payload from customs in Frankfurt on a holiday weekend!
 - AFRL/RQ, JHU/APL, and DLR completed initial integration and testing milestones at DLR MORABA (4/30/21 to 5/6/21)
 - Environmental testing at Airbus Ottobrunn completed a day early (5/12/21)!
 - APL and AFRL/RQ returned home 5/13
 - Finalized range attendee list for June 2021 campaign and working travel logistics with all organizations
 - Flight campaign at the moment is ON for June 2021!
 - Integration summary 3 May (DLR MORABA)
 - Unpacked payload and set up gear at DLR
 - Lifted payload to table in tandem with DLR systems, unassembled
 - AFRL system checkouts (payload in good health!)
 - Crate and payload appeared undamaged
 - Instrumentation checkouts of payload initiated
 - A few more sensors appear down compared to December 2019, some of these were repaired via scuffing
 - ~13 Medtherms total were either previously broken or not working at arrival to DLR
 - 4 were successfully re-scuffed
 - Additional 3 were re-scuffed but still reading a little off, might need additional scuffing
 - AFRL and DLR systems connected and sample flight simulation completed
 - DLR had two TM receivers (2 channels each) except one was broken, limiting the TM test to 2 channels (DLR housekeeping stream and one TM stream at a time). This would later be corrected.
 - Tested RF interference btw. AFRL and DLR systems
 - Integration summary 4 May (DLR MORABA)
 - Repair and re-scuffing of ~7 Medtherms
 - DLR debugged a software issue causing some dropouts in the initial TM test
 - Familiarization with handling / lifting
 - AFRL set up GPS
 - Ran electromagnetic interference checks on payload systems with TM and GPS. Payload passed this test!
 - Complete payload meets for the first time!
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- Conducted an initial “fit check” of the complete payload for the first time, vertical assembly
 - DLR repaired TM receivers allowing a first initial test of all 4 TM streams at once!
 - Integration summary 5 May (DLR MORABA)
 - Practiced lifting and ideal contact points on Flight Geometry for CG/MOI test fixture
 - Let us finalize the test fixture
 - Gave DLR lots of experience handling/moving the payload into different configurations
 - Removed GHI handling fixtures for preliminary assessment of the CG of the complete payload
 - Our approximate CG is about ~1cm aft (.03 calibers) of design, potentially due to movement of the GHI PCB132 DAQ
 - Tom worked with DLR to utilize existing Tungsten Alloy blocks to add underneath fairings
 - Potentially for further ballast, but also potentially for spin balancing
 - Dave and DLR worked on flight telemetry timings
 - TM stream 2 needed to be extended after ascent to transmit the PCB132 spectra
 - Integration summary 6 May (DLR MORABA)
 - Airbus Environmental Testing Summary (7-12 May)
 - Mass properties measurements
 - CG of payload alone ended up slightly aft of design (~1cm)
 - However, the weight was also higher, which likely means no overall effect on stability
 - +9 kg total across DLR, AFRL, and APL components!
 - If this remains, might result in a drop of approximately 0.1 Mach in experiment windows
 - We got some beautiful photos of the payload on the CG scale
 - Vibration testing
 - Three runs in each axis:
 - Low-level frequency sweep (pre)
 - High-level random frequency
 - Repeat of low-level sweep (post)
 - BOLT exhibited resonance in the ~20-25 kHz frequency range in the first run, these frequencies were skipped for the remaining high-level runs
 - We possibly lost an additional Medtherm during vibe testing (will verify in final checkouts as Estring)
 - Dave also acquired PCB132B data during vibe, so we can look at the spectra for issues. We will look at this data at Estring.

BOLT FLIGHT CAMPAIGN DAY 1: Thursday 6/10/2021

- Summary
 - Official first day of the campaign consists primarily of the arrival of the DLR MORABA team via charter aircraft Oberpfaffenhofen→Kiruna, arrival anticipated evening 10 June
 - A small team including APL, NASA, and AFRL/RQ arrived on site to Esrange Space Center 7-9 June, and has spent some time planning final preparations of the BOLT payload and working on post flight analysis tools
 - The largest issue ahead for the campaign consists of additional inspections to certify the S31 first stage motor for flight after the discovery of a broken weather seal during long term storage. The draft nonconformance report for the booster is attached which outlines the additional motor inspection steps.
- Accomplishments
 - Arrival of Scott Berry/NASA 7 June, arrival of APL team (Wheaton, Berridge, Wolf, Araya, McKiernan) 8 June, arrival of Dave Adamczak 9 June, arrival of DLR MORABA via charter aircraft 10 June, arrival Popkin and HYFLITS team 10 June
 - BOLT payload arrived to Esrange via express transport on 9 June following solution of export paperwork challenges
 - BOLT Flight Requirements Plan (FRP) Version 1.0 issued by DLR
 - APL team met on site to finalize tasking and plan for final preparations of the Flight Geometry, including:
 - Make mold measurements of the final joint steps
 - Re-scuffing of all thermocouple sensors
 - Manual testing of sensors while Dave is recording data (temperature, pressure, heat transfer)
 - Photographs and documentation of sensors
 - Final cleaning of experimental surfaces
 - Application of RTV to closeout holes on forebody
- Issues
 - S-31 Weather Seal
 - DLR has provided a draft NCR (non-conformance report) for the damaged first stage S-31 weather seal. No damage in any other regions was found.
 - After discussions with the vendor (IAE), storage logger data examination (temperature and humidity), and SSC, DLR recommends the motor is able to fly but with specific conditions met.
 - A series of extra inspections and tests, including possible X-ray examination of the propellant block, are planned by DLR during the campaign to provide additional assurance the motor is able to fly
 - Previous issues regarding travel, payload shipment, and coronavirus safety mitigations have been resolved

- Plans for Next Day Efforts (**11 June**)
 - Unpacking of containers and payload (all)
 - Initial inspections of S31 motor (DLR)
 - Fit check of Motor Adaptor to IO second stage (DLR)
 - Attempt to complete final joint step mold measurements (APL and NASA)
- Outlook/Target Date for Launch (**no earlier than 18 June**)
 - Campaign activities have not yet begun due to the pending arrival of DLR on 10 June, however additional activities are anticipated compared to the pre-campaign plan due to extra work on inspections of the S31 motor. These extra inspections are accounted for in the notional schedule below from DLR.
 - First “Hot Countdown” is anticipated the evening of 18 June, with potential lift off the morning of 19 June (Sweden time GMT+2)
 - From DLR: “As we have a launch window in the early morning hours, currently the plan indicates that we try to go for a practice CD throughout the day time on June 17 including the balloon launches off site, and then rest throughout the following day until say 22h00 LT to start into the hot CD, that would be June 18, but lift off then only in the morning of June 19.”
- Additional Items of Note
 - BOLT has a new mission description post on the SSC web site:
<https://sscspace.com/blog/2021/06/04/bolt-1/>

Nominal Mission Schedule as of 6/9/21 provided by DLR (Date Format = DD.MM)

Day	AM	PM	Remarks
08.06. TUE	Arrival of container transport (two containers)	Unloading of container in launching area by SSC (tbc);); arrival of PI and APL team	Crane required
09.06. WED	Arrival of express transport with BOLT payload	Storage of BOLT payload in Church, arrival of Exp P/L Engineer	Check for locks/seals
10.06. THU		Arrival of US PM and HYFLITS team, Arrival of MORABA team	
11.06. FRI	Daily morning meeting, unpacking of container in P/L Assembly S31 inspection	Installation in P/L Assembly, income checks S31 inspection; IO MA fit check Arrival of AFRL team	
12.06. SAT	P/L preparations for flight simulation test, EGSE setup in P/L Assembly IO leak test/pressure test, S31 inspection	P/L preparations for flight simulation test, EGSE Setup in P/L Assembly S31 inspection Possible balloon test flights from Esrange	Discuss possible balloon flight tests

Day	AM	PM	Remarks
13.06. SUN	P/L flight simulation test and final preparations IO TC and fin installation, IO nozzle extension installation , S31 inspection	P/L flight simulation test and final preparations IO phys. prop. measurements S31 inspection	IO ready
14.06. MON	P/L final assembly and phys. prop. measurements S31 inspection	P/L system check, Setup of EGSE in Blockhouse/Dome and Launcher, S31 inspection/decision	P/L ready
15.06. TUE	S31 TC and fin installation Possible P/L troubleshoot, Daily met briefings	S31 igniter/SAD installation S31 phys. prop. Measurements, Possible P/L troubleshoot	S31 ready
16.06. WED	S31 loading onto MAN2 IO loading onto MAN2, fixation of motor and elevation	P/L loading onto IO Installation of all umbilicals on MAN2 and rigging, P/L systems check	Vehicle on MAN2
17.06. THU	Practice Countdown w/ HYFLITS balloon launches from remote location	Practice countdown cont'd, post operation meet and Flight Readiness Review	Earliest possible test CD w/ remote balloon launches
18.06. FRI		22h00LT 1 st Hot CD HYFLITS balloon launches	
19.06. SAT	1 st Hot CD cont'd HYFLITS balloon launches		

BOLT FLIGHT CAMPAIGN DAY 2: Friday 6/11/2021

- Summary
 - Today was the first major day of campaign operations. It consisted primarily of unpacking and checking out the various systems including the payload.
 - DLR has determined via fit check that the S31 first stage is round, and not flattened, providing additional assurance that the motor had not been dropped. A full inspection of the motor propellant grain for cracks is underway. 90% of the propellant has been inspected with no cracks. If a crack is found, it indicates the motor was dropped, and it would not be used (postponing the mission). The remaining 10% is in the aft region of interest near the broken weather seal. It has been determined that X-ray inspection is not required and the borescope inspection will be sufficient.
 - Detailed joint step and surface mold measurements were completed by APL and NASA to fully characterize the joint steps just prior to flight.
 - Instrumentation inspections and preparations are also underway on the payload, with additional work expected to continue on Saturday 12 June.

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- AFRL Safety Review Board conducted a review of the BOLT flight campaign and assigned it a “low risk”
 - Accomplishments
 - We held the first daily morning meeting at 0830 hours local time, which was conducted virtually via Microsoft Teams for COVID safety reasons. The APL, NASA, DLR, AFRL, and SSC personnel got to introduce themselves to one another. Summaries of planned work and a daily schedule were briefed.
 - Checked shipping container contents, inspected payload tamper and locks, inventory of equipment and supplies. Unpacked payload and equipment, set up AFRL and some DLR systems for initial testing of payload and flight simulation countdowns.
 - DLR performed an inspection and powering of their mobile telemetry (TM) station which had been left on site at Esrange. They had progress in the setup of the mobile TM and communications between their systems and the range’s systems today. They had to replace some broken parts in the TM station.
 - Completed mold measurements of the joint steps and surface finish of various regions of the Flight Geometry (primary and secondary side). These mold measurements will be later analyzed by NASA Langley and will be compared to previous mold measurements taken by Purdue of the same features. The mold measurements complement various other joint step measurement techniques attempted by APL and others (optical photogrammetry, depth gauge measurements, optical scans, etc.).
 - DLR completed initial inspections of the S31 first stage. They found the motor was round which reduces potential of the weather seal being damaged by a drop. Inspections of the propellant are underway with a borescope to look for cracks and separations. Thus far, the propellant and motor are in good condition (having inspected 90% of the propellant thus far). X-ray measurements will not be required, confirmed by AFRL SME’s as well as DLR. A group of specialists is traveling to Esrange with a better scope for inspecting the 10% remaining aft end of the propellant which is the area of interest. DLR and IAE have decided that X-ray inspections are not required.
 - AFRL/RQ, AFOSR, and DLR met with the AFRL Safety Review Board (SRB) led by the AFRL Safety Office for BOLT to cover permission to conduct the launch operations, personnel working and flight launch safety, and general public casualty estimation. Following the SRB Review, the BOLT mission was assigned a “low risk”.
 - The Flight Geometry was placed in a lateral fixture with the lifting hardware removed for maximum instrumentation access. It will remain in this position while the APL team conducts final preparations of the payload sensors and surface for the flight experiment. Today, detailed macro photographs were taken of all 48 Kulite sensors to document sporadic plugged holes in the B-screens. Any sensors where some of the holes plugged might experience a slightly reduced frequency response, but it is not expected to impact the data due to relatively low sampling frequencies for these sensors (maximum 70kHz
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- sampling, but mostly 15 kHz). The macro photos are to document which Kulite sensors have the partially plugged holes.
- The HYFLITS balloon team has set up their tracking system on the SE corner of the balloon pad. They have assembled a couple of balloon payloads for launch, but rainy forecasts might delay the launches.
 - Issues
 - S-31 Weather Seal
 - AFRL solid rocket booster SME's were consulted to determine if the actions proposed by DLR are reasonable.
 - The AFRL SME's do not think the x-ray inspection is necessary but that it couldn't hurt.
 - AFRL SME's concur with the DLR plans to inspect the motor, documented in the draft Non Conformance Report, and that if the motors passes the inspections it will be fit to fly.
 - DLR found the motor to be round, reducing any suspicion of the weather seal damage being caused by a drop
 - Inspection of the propellant grain is ongoing, with thus far no cracks observed
 - Plan is to have an acceptance review ~3 days from now summarizing the findings and have major parties sign the final non-conformance review to declare the motor fit for flight.
 - Plans for Next Day Efforts (**Saturday 12 June**)
 - Instrumentation preparations on the Flight Geometry, including re-scuffing all the Medtherm sensors. All sensors will then be tested and operational status verified, with debugging as needed of individual sensors.
 - Macro photographs of the joint steps are planned for documentation purposes.
 - Inspection of the 10% remaining propellant in the aft area of the S31 booster, which is the region near the weather seal
 - Communication checks on the DLR service modules and ACS systems, to check installation of communications with the range infrastructure
 - Flight simulation testing of the attitude control system (ACS) involving firing of the nitrogen cold gas nozzles, to check the relation of the navigation system with the attitude controllers
 - Mobile TM station additional setup. Plan is to spend today repairing a broken pipe in the TM station with the local workshop as Esrange.
 - HYFLITS balloon team is working on some software updates ahead of their future launches that are dependent on the weather (rain in forecast).
 - Outlook/Target Date for Launch (**no earlier than 18 June**)
 - No changes to projections, activities are still in line with the nominal schedule
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- Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 3: Saturday 6/12/2021

- Summary
 - Day 3 consisted of additional checks of the S31 motor. Thus far no cracks have been identified. All data seems to support the theory of a depressurization event causing the damage, rather than a drop. The weather seal was reattached. A revised nonconformance report is expected Monday 14 June ahead of a planned acceptance review for flight readiness for the S31.
 - Detailed checkouts of most of the BOLT science instrumentation were completed with no major issues discovered. The instrumentation is in good working order ahead of the flight with no additional broken sensors found.
 - Additional setup of range and telemetry communications was completed.
- Accomplishments
 - Completed joint step macro photos for documentation of the steps, as they appeared before flight. Completed documentation of locations/dimensions of fiducial markings for the locations that joint step molds were taken.
 - Additional macro photos on the Vatel heat flux gauges were taken for documentation purposes
 - Checkouts of BOLT science instrumentation. Overall sensor health is as anticipated, with only sporadic failed sensors observed earlier. A few malfunctioning Medtherms appear to have been recovered via the re-scuffing process.
 - All 16 mean pressure Kulites were verified, and calibrations cross-checked against a handheld calibrated vacuum pump.
 - The medium-frequency Kulites are more difficult to assess, but 31 of 32 appear to be operating, with one sensor potentially not working.
 - The Medtherms were all re-scuffed due to the dominant age of the first junctions (~2 years). Re-checks of the Medtherms, as well as the Vatel heat flux gauges, were completed with a heat gun.
 - Created a makeshift cover for the Flight Geometry out of anti-static material, to protect the experimental surface from moisture and grease while it is on the launcher
 - DLR completed attitude control system nitrogen gas firing simulation, verifying that it was working properly
 - DLR finished pressure test and installed nozzle extension and tail can on the second stage (Improved Orion) and conducted a fit check to the motor adaptor
 - Following sensor checkout, the DLR service module was attached to the BOLT forebody and the statuses of the transmitters and networks were checked from the payload near the launcher area, to the DLR TM station.

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- AFRL and DLR conducted testing of transmission of flight data and information from the launcher area to the Dome (a building near the balloon launching pad where the science team will set up for the flight). Thus far some connections to the Dome need to be figured out for various systems.
 - Issues
 - S-31 Weather Seal –
 - DLR did not find any cracks in the S31 motor propellant thus far (90% inspected). They did find a piece of red silicone material about 0.5m upstream of the weather seal, providing additional assurance that the broken weather seal was likely due to a break from a pressure differential (the going theory).
 - They added RTV to reattach the weather seal, along with applied pressure differential. The seal will be checked tomorrow.
 - Then an inspection of the final 10% propellant grain will be done through a new hole created in the new seal. In the end, the “seal” is not required for ignition, but the seal was recreated with RTV mainly to contain the old debris from the weather seal and ensure it is ejected properly.
 - Plans for Next Day Efforts (**Sunday 13 June**)
 - DLR will conduct leak checks on the repaired S31 weather seal to ensure the repair was successful.
 - Preparations of the mobile launcher (check rail, grease rail, etc.)
 - HYFLITS may attempt some balloon launches in late afternoon, pending check of the weather
 - Additional communication checks and simulation runs of the Service Module (SM) and Attitude Control System (ACS). These will check communication software issues between the inertial navigation system in the SM with the ACS controllers.
 - Begin attaching fins to the Improved Orion second stage
 - Begin final surfacing cleaning and removal of tape residue from the Flight Geometry surfaces
 - Check out PCB132 sensors and verify operation
 - Outlook/Target Date for Launch (**no earlier than 18 June**)
 - No changes to projections, activities are still in line with the nominal schedule
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 4: Sunday 6/13/2021

- Summary
 - Day 4 was probably the last day in which full access to the BOLT Flight Geometry was available, and the time was used for cleaning of the experiment surfaces and

completion of instrumentation photographs. Partial access to the payload is likely on later days to address any small final cleanings and instrumentation debugging, but overall the Flight Geometry is ready for flight.

- DLR discovered a software problem related to the timing and communications of their onboard systems, causing strange behavior of a GPS timing message used onboard for the flight timing and navigation systems that behaves significantly different from one day to another. This is the biggest issue at the moment and risks causing some delays on the complete payload integration and readiness.
- Thus far there is a slip of 1 day for the complete payload flight simulation test, which is being postponed to Tuesday 15 June.
- The S31 repaired weather seal spent today with the RTV curing, and final inspections are planned for Monday 15 June of the propellant. Motor acceptance review is tentatively planned for Tuesday 16 June.
- Work has finished with the second stage Improved Orion motor (fins installed, it is ready)
- The launcher is ready to accept the vehicle after inspections and testing yesterday
- Accomplishments
 - Conducted cleaning and detailing of the experiment surfaces, removing tape residue, residue from the handling fixture rings (epoxy that had seeped out during thermal testing), remnants of RTV, fiducial markings, etc.
 - Took macro photos of all Medtherm sensors for documentation purposes. Additional mold measurements were made over a few of the Medtherm sensors for any future characterization of the roughness induced by the surface junction.
 - Uncovered the eight PCB-132 sensors and did final preparations and removal of excess RTV from the installation process, as well as cleaning. Macro photographs of the PCB-132 sensors were also obtained.
 - Began to fill closeout holes on the Flight Geometry gutter surfaces with Permatex , to provide a smooth aerodynamic surface for the gutters. The primary experiment (heavily instrumented) gutter surface was filled first as it was accessible. The secondary gutter RTV holes will be filled later when the payload is in a different configuration with that surface accessible. Some of the joint seams within the gutter were also filled.
 - DLR inspected and began preparations to the mobile launcher. The rail has been greased. Setup of AFRL communication systems to the launcher are underway. The launcher is housed underneath a movable building, which slides away on rails approximately an hour before a launch attempt. The launcher has been deemed ready to accept the vehicle.
 - Completed preparations on the Improved Orion and it is ready for flight

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- HYFLITS conducted their first balloon launch! They have not yet solved their TM issues, so they hope to recover this launch. Luckily, it landed near a road in Kiruna so they might be able to pick it up without the helicopter on Monday.
 - Ground network signal distribution issues have been solved
 - Issues
 - S-31 Weather Seal
 - The RTV is successfully cured, plan for Monday is to spend the day doing inspections of the propellant with the borescope
 - Tuesday 15 June it is anticipated that all data will be available to decide whether the motor is flightworthy or not
 - SM/ACS software issues
 - DLR discovered a software problem related to the timing and communications of their onboard systems, causing strange behavior of a GPS timing message used onboard for the flight timing and navigation systems that behaves significantly different from one day to another.
 - This issue can cause sporadic loss of communication between the inertial navigation system and the controllers
 - Saturday and Sunday the code stopped working after working for a very long time.
 - This has been tracked down to a very few lines of code, which seems correct, but somehow the output of these lines is not correct.
 - Since it is Monday, DLR will be getting support from home base Oberpfaffenhofen with additional software testing and will be working this all day today.
 - Plans for Next Day Efforts (**Monday 14 June**)
 - Complete inspections of the S31 propellant and all remaining motor inspections ahead of planned acceptance review on 15 June
 - Debug and hopefully solve DLR software issue with GPS timing working together with home base Oberpfaffenhofen
 - Connect payload again and do more checks of communications with the range infrastructure to determine if data can be sent to the Dome for the science control room
 - Outlook/Target Date for Launch (**seems like we might be running ~1 day behind due to software issues, meaning a launch no earlier than June 19 if this holds**)
 - Activities are still in line with the nominal schedule. Progress on Monday 14 June of preparation of the complete DLR/AFRL/APL payload will be a key indicator. Any additional software issue delays might cause a slip in schedule by a day or two.
 - Launch windows will be 0200-1400 local time (GMT+2) starting on ~19 June
 - Meteorological (Met) briefings will begin starting Wednesday 16 June
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- Additional Items of Note
 - APL is set to coordinate with AFOSR and AFRL public affairs offices on a short press release and social media video ahead of the launch windows

BOLT FLIGHT CAMPAIGN DAY 5: Monday 6/14/2021

- Summary
 - Today was a very productive day!
 - The source of the software communication issues was identified by DLR and is being corrected
 - The S31 motor inspection has been completed and the motor is being recommended for flight by DLR, after a complete inspection of the propellant it was found in good working order
 - Overall, we are probably about a day behind the nominal schedule, although the first official countdown has not yet been set. It would appear we are tracking for a first attempt no earlier than 19 June.
- Accomplishments
 - A leak test of the motor repaired seal was successful. Manual pedaling of the downstream seal was done to enable borescope investigation of the aft propellant grain.
 - Inspection of the S31 motor concluded with no evidence of cracks. DLR is recommending to accept the motor for flight. An acceptance review is planned for Tuesday 15 June.
 - DLR discovered the reason for the software issue and is currently working on a fix.
 - The GPS receiver sends a variable that is the number of seconds into a week, beginning at 0000 Sunday.
 - DLR's code had only ever encountered this variable with six digits. After about 0300 Monday in any given week, this variable has six digits. However, when it was tested for the first time on a Sunday while at the range, the variable only had five digits and sent the sixth digit as a blank. This caused issues to the DLR software that only occurred on Sundays!
 - Now that the issue has been discovered, DLR will work to fix the code and do verification testing such that flights will be allowed on Sundays to open up weather possibilities.
 - AFRL and DLR were able to successfully send TM data from the launcher area to the science team control room at the Dome. This verified complete functionality of the ground distribution network.
 - Completed RTV of closeout holes for secondary side gutter. Some touch up RTV may be needed especially in the primary side gutter that is instrumented, to ensure a relatively smooth surface finish at flight start.

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- AFRL is still working some final issues with communications between the launcher DLR systems and the payload controls, but has found a solution to the problems and will test it tomorrow. This issue involves an interface between the DLR and AFRL serial interfaces and was causing extremely slow updates back/forth to the payload.
 - Iterating on countdown procedures between ESC, DLR, AFRL, APL. Version 0.6 draft countdown has been circulated.
 - HYFLITS was able to recover their balloon launch from Sunday via access from a road near Kiruna
 - Issues
 - S-31 Weather Seal
 - Inspections have been completed
 - A final nonconformance report (NCR) is due to be issued by DLR recommending the motor for flight
 - An acceptance review is planned for Tuesday 15 June for all parties to review the findings
 - SM/ACS software issues
 - The source of the software issue was identified. A software fix has been proposed and is being implemented.
 - Will continue to monitor this issue and follow up on any required validation of the new changes.
 - Plans for Next Day Efforts (**Tuesday 15 June**)
 - Motor acceptance review at 1000 Tuesday to summarize the S31 inspections and accept the motor for the flight
 - DLR will be implementing and testing a firmware update to their payload systems to patch the “Sunday bug” that affected the GPS communications onboard.
 - AFRL will set up and test a fix on communications between the DLR serial interface and the payload
 - Perhaps tomorrow afternoon we will attempt a flight simulation test of the complete payload, expected ca. 1400
 - Review of countdown procedure draft by all parties
 - Prepare the DLR MAN2 launcher and tower for potential loading the motors
 - Outlook/Target Date for Launch (**seems like we might be running ~1 day behind due to software issues, meaning a launch no earlier than June 19 if this holds**)
 - No changes to projections, activities are still in line with the nominal schedule
 - Meteorological (Met) briefings will begin starting Wednesday 16 June
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 6: Tuesday 6/15/2021

- Summary
 - DLR issued a patch/correction to their software based on the findings of the issue, with support of other engineers at DLR Oberpfaffenhofen
 - Day 6 concluded with two successful flight simulations of the complete APL/AFRL/DLR payload. The tests went well and systems appear close to ready to load onto the launcher.
 - DLR spent a long day preparing the S31 motor for flight after summarizing the inspections of the nonconformance broken weather seal to the Esrange Safety Board. The Esrange Safety Board has accepted DLR's recommendation to fly the motor!
 - There is a new COVID-19 contact tracing effort involving SSC staff, including the range safety officer, that could cause delays...
- Accomplishments
 - AFRL successfully tested the new ground control configuration and is confident they can control the payload power and commands from the range ground network in coordination with the DLR systems
 - DLR completed a software patch to the DMARS system issue, which caused some dropouts from the IMU data. They did verification testing of the patch fix at DLR Oberpfaffenhofen without identifying any issues. The fix causes slightly higher CPU load on the onboard computers to add some additional loops.
 - Performed two complete flight simulation tests of the payload that were both successful. These tests are hardware in the loop (HIL) to simulate the flight with the payload on internal power and transmitting across the range to the receiving stations. The tests checked out the timing of mission events, software, and communications to the range infrastructure. Science TM data was later analyzed to confirm quality, with no dropouts. During the flight simulation, DLR was able to observe the DMARS IMU software issue occurring with the patch correcting for it, so they are pleased with the performance of the software patch.
 - Held acceptance review for S31 first stage nonconformance (broken weather seal). This review was presented by DLR's launch team lead summarizing the findings from the inspections of the motor. The review was presented to the Esrange Safety Board who would ultimately decide whether or not to accept the motor for flight, which was DLR's recommendation.
 - DLR installed the S31 first stage fins and igniter and prepared the motor for loading onto the launcher, anticipated tomorrow Wednesday 16 June. The Improved Orion had previously been prepped for loading.

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- HYFLITS launched a second balloon in the afternoon. They have been unable to solve their telemetry problems so are now planning to prepare all their balloons with onboard data storage and helicopter recovery.
 - Issues
 - S-31 Weather Seal
 - DLR has recommended the motor for flight
 - Formal acceptance of the recommendation by the Esrange Safety Board has been completed
 - This issue is resolved and will no longer be tracked after today.
 - SM/ACS software issues
 - A patch has been delivered to the DLR payload and the payload performed well in two flight simulation tests.
 - This issue appears to be resolved and will no longer be tracked after today.
 - COVID-19 contact tracing involving other campaign (HADT)
 - Four positive COVID cases have been identified in a concurrent ongoing campaign parallel to BOLT on range (High Altitude Drop Test) over the past few weeks. There was one additional case identified today.
 - Although the mission safety concept avoids interaction between BOLT and HADT teams completely, there may be some SSC personnel involved in contact tracing awaiting testing that could result in personnel issues the next few days, with impacts to be determined on the BOLT campaign. Key personnel would include the SSC range safety officer who is required for motor loading onto the launcher to occur tomorrow.
 - Plans for Next Day Efforts (**Wednesday 16 June**)
 - Assess impacts of the SSC staff contact tracing on the overall schedule
 - Installation of the S31 launch lugs and preparations of the motor for loading
 - Attachment of mission decals to first stage S31 motor
 - Load motors onto MAN2 launcher, and perhaps also the payload
 - Outlook/Target Date for Launch (**A more definitive update on potential first launch window will likely be discussed at today's initial Met briefing, but it is likely no earlier than 19 June. Contact tracing threatens further delay.**)
 - Meteorological (Met) briefings will begin starting today
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 7: Wednesday 6/16/2021

- Summary
 - A major setback today, as a contact tracing effort by SSC prohibited their staff from entering the base until receiving a negative COVID test. This meant there were no SSC

flight safety officers to supervise the planned motor loading onto the launcher. The motor loading was postponed, delaying the mission by roughly a day more. The hope is that these staff members might be cleared by afternoon tomorrow, enabling motor loading later in the day tomorrow.

- In the absence of the motor loading, the team took the opportunity to complete payload assembly and to move the ground support stations for the telemetry and payload systems to the final building where the flight will be monitored by personnel from DLR, AFRL, and APL.
- Accomplishments
 - Installation of the tail can and launch lugs onto the S31 was completed in the morning, and the S31 is ready for loading onto the launcher
 - DLR, APL, and AFRL/AFOSR completed installation of decals on the S31 motor from the organizations involved in BOLT
 - AFRL/RQ completed final checks on the TSM/PSM. The interior was then reconfigured for flight, removing a battery controller, and tying off final wire bundles. All bolts on the TSM and PSM were torqued with Loctite applied, then RTV applied.
 - The BOLT payload (Flight Geometry, TSM, and PSM) were then assembled with the DLR service module to create the complete payload. The complete payload was oriented vertically in the Church (launcher area building) for a communications check.
 - The AFRL/payload monitoring and control equipment was relocated to the Dome (building near the balloon pad) due to limited space in the Church. AFRL payload control systems, computers, and equipment were packed and relocated to the Dome ahead of the communications check. Verified that the new setup in the Dome could connect to and control the payload.
 - Began to set up science team monitoring stations for the flight
- Issues
 - COVID-19 contact tracing involving other campaign (HADT)
 - We lost the ability to load the motors today due to two required SSC personnel who are banned from entering the base until receiving the results of their PCR tests
 - This issue could worsen the schedule if the test results are not returned in a prompt fashion
 - Unfortunately, there is considerable uncertainty to the impacts and potential resolution of this issue which is largely out of our control...
- Plans for Next Day Efforts (**Thursday 17 June**)
 - While awaiting for the negative tests to return for the two SSC personnel required for motor loading, the team will be given the morning off. Report time will be shifted from 0830 to 1230 tomorrow beginning with the daily meteorological briefing at 1230.

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- Assuming the flight safety officers from SSC can be cleared to come on base, the day will commence with loading of the motors onto the launcher
 - If motor loading can be completed, depending on how late we can go we will attempt to load the payload onto the motors
 - Outlook/Target Date for Launch via latest meteorological briefings (**all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified**)
 - Saturday 19 June (Wind=RED, models show likely unfavorable winds with precipitation exiting the area). Note that due to delays in motor loading this window may not be achieved regardless of the weather.
 - Sunday 20 June (Wind=YELLOW, models show borderline winds but favorable precipitation)
 - 21+ June (not yet categorized, but long-term weather trends seem to improve early week of 21 June)
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 8: Thursday 6/17/2021

- Summary
 - Today was a day of halted operations as we awaited COVID test results for the SSC personnel who would be needed to support motor loading
 - The situation worsened in the evening. The mass testing of the SSC department returned four positive tests, and SSC decided to cancel motor loading until they could understand how many of the remaining tests would come back positive too.
- Accomplishments
 - The science team was able to do some setup of the monitoring stations and assignments of roles during the down time
- Issues
 - COVID-19 contact tracing involving other campaign (HADT)
 - We do not know the results of the full testing of the rockets and balloons department yet
 - There is some worry that
 - DLR has been working with SSC on a new safety concept that would be more stringent and allow countdown operations to occur. We do not know the details of that plan yet but it sounds promising to enable us to continue the mission.
- Plans for Next Day Efforts (**Friday 18 June**)
 - Awaiting additional information from Esrange Crisis Board meeting on allowable operations including motor loading
 - Report time shifted to 1230

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- Outlook/Target Date for Launch via latest meteorological briefings (**There is potentially an opening Monday early in the countdown window**) (all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified)
 - Saturday 19 June and Sunday 20 June we cannot achieve due to the delays
 - Monday 21 June looks promising early in the countdown window, and perhaps might be achievable if we can load motors and payload Friday
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 9: Friday 6/18/2021

- Summary
 - No additional SSC COVID cases were identified, and the range gave permission for motor loading that commenced today. The motors, payload, and ground support equipment were loaded throughout the evening.
 - Unfortunately, after loading and initial checks two issues were identified
 - One of the payload battery chargers (battery 1) is disconnected. This is likely just an external cable connection issue in the tower but without access to the launcher this cannot be confirmed.
 - **The bigger issue is that one of the payload batteries (battery 2) was reading zero voltage on the initial checkout.** This battery had been performing a bit lower during HILS testing but was holding charge and performed well in the flight simulation tests prior to loading. The cause of this issue could be a broken connector or it could be a dead battery. The mitigation options vary in time and complexity, but many debugging steps would require separating the payload from the motors, and perhaps bringing it and the GSE all the way back to the Church for debugging. If the battery is in need to replacing, it would have to be accessed by removing one of the panels on the TSM which is a more involved operation.
 - Debugging of the battery issue cannot commence for complex operations on Saturday due to the off day required for SSC and DLR personnel. But, some limited debugging is planned.
- Accomplishments
 - Obtained permission to load the motors, and support of SSC personnel for that activity
 - Loaded S31 and IO motors onto the rail in the late afternoon
 - Prepared the payload and loaded the payload onto the rail ca. early evening
 - Loaded ground support equipment (GSE) into the tower in the late evening
 - Conducted an initial check of the payload systems ca. midnight!
- Issues
 - Payload Battery 2 reading zero voltage

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- This could delay us a day if we need to go inside the payload and change the batter, as it would be a rather complex operation
 - Payload Battery 1 charger offline
 - Plan is to assess the power connections on the external GSE in the launcher tower as soon as access can be granted
 - COVID-19 contact tracing involving other campaign (HADT)
 - No further cases have yet been identified, and altered safety precautions are being enacted by SSC to try to maintain safe operations
 - Plans for Next Day Efforts (**Saturday 19 June**)
 - Saturday is a planned off day for SSC and DLR, although some limited DLR personnel are planning to help AFRL start to debug the battery issue today
 - Outlook/Target Date for Launch via latest meteorological briefings (all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified)
 - The Sunday window will not be possible.
 - Monday would be possible only if the battery issue can be corrected in a timely fashion during the off day.
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 10: Saturday 6/19/2021

- Summary
 - Today was a planned off day for SSC and DLR personnel
 - Some limited checkouts of the Battery 2 issue were completed, and based on those findings **the battery will need to be replaced on Sunday**. This will require removing the payload from the stack and bringing it to the Church for the operation.
 - There will be no launch attempt on Sunday due to the above delay
- Accomplishments
 - None, today was an off day
- Issues
 - Payload Battery 2 reading zero voltage
 - This could delay us a day if we need to go inside the payload and change the batter, as it would be a rather complex operation
 - Payload Battery 1 charger offline
 - This will be checked today, but the ground support equipment will be removed again to move back to the Church so it is not a high priority
 - COVID-19 contact tracing involving other campaign (HADT)
 - Thus far, no further cases have been reported and the team is adhering to the strict DLR COVID-19 safety plan
- Plans for Next Day Efforts (**Sunday 20 June**)

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- 0800 – DLR launch team to remove the payload from the rail and transport it to the church
 - 0830 – regular morning team meeting
 - Following the team meeting, AFRL to remove RTV and bolts from one half of the TSM shell to access and replace the dead battery
 - Perform checkouts of the replaced battery systems (will require relocating ground support equipment from the launcher tower to the Church)
 - If checkouts go well, perform a full simulation in the Church
 - If able, transport repaired payload back to launcher and install on rails, followed by reconfiguring the Flight Geometry for flight (install weights, fairings, RTV, etc)
 - Outlook/Target Date for Launch via latest meteorological briefings (all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified)
 - Earliest possible window is now Monday TBD, depending on progress on battery replacement today
 - Favorable winds but some rain in forecast Tuesday and Wednesday, launch would depend on one hour free of precipitation. Winds are much better on Wednesday.
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 11: Sunday 6/20/2021

- Summary
 - The payload was removed from the rail and brought to the Church, and the dead battery #2 was successfully replaced
 - However, another issue was discovered when we lost the ability to recharge battery #2 either manually or remotely.
 - Debugging the issue required removing a different panel from the TSM and delaying returning the payload to the rail
 - Working into the night, the issue was discovered... a bad solder joint on the umbilical board. This could perhaps have been related to the discharge of battery #2 previously. The issue was corrected by resoldering the joint, then was tested, and the TSM/PSM was reassembled ca. midnight. The theory is that the solder joint could have been damaged from repeated board flexure from installation of the umbilical cable, in particular the final installation of the umbilical when the payload was last loaded onto the stack.
- Accomplishments
 - Discovered and then corrected a potential root cause of the battery #2 discharge, related to a bad solder joint on the umbilical interface board inside the TSM
- Issues
 - Payload Battery 2 reading zero voltage

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- Removed old battery and replaced with a new one
 - Discovered in the process a bad solder joint on the umbilical interface board which was later corrected as well
 - COVID-19 contact tracing involving other campaign (HADT)
 - Thus far no further cases have been identified
 - However, a few personnel had not yet received their negative test results which does risk not having a full SSC operational team for impending countdowns
 - Plans for Next Day Efforts (**Monday 21 June**)
 - Complete a final check of the repaired TSM/PSM from last night, and if all looks good, tie down the aft wire bundles in preparation for mating with the DLR service module
 - Complete a final flight simulation check of the complete payload with DLR in the morning to ensure everything is operational
 - Load the payload back onto the rail
 - Complete final assembly of the payload on the rail (fairings, balance weights, RTV)
 - Move towards a flight ready posture by the end of the day
 - Outlook/Target Date for Launch via latest meteorological briefings (all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified)
 - Tuesday: TBD, we need to get through the day Monday with a lot of work remaining, and the winds for Tuesday looked unfavorable
 - Wednesday: Without further issues it is likely we will make an attempt for Wednesday. Winds are favorable and the only threat appears to be unpredictable precipitation that seems likely.
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 12: Monday 6/21/2021

- Summary
 - The payload was repaired and installed on the launcher, resulting in a flight-ready vehicle by the end of the day!
 - A first launch attempt is currently planned for 0200 Wednesday local time (8pm ET Tuesday evening in the USA)
- Accomplishments
 - Diagnosed and corrected broken solder joint on PSM umbilical connection board (ca. 0100)
 - Assembled complete payload and conducted a flight simulation test from the Church to verify operability (late morning)
 - The payload was then moved back to the launcher and installed on the stack. DLR completed rigging of the umbilical cables with tethers and pull cables. (completed ca. 1730)

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- APL installed the fairings and balance weights, with Loctite and RTV, and completed RTV of the closeout holes, and did a full inspection and cleaning of the experimental surfaces (completed ca. 1930)
 - The ground support equipment setup was tested one final time with verified operability
 - Finally, the tower was retracted to expose the vehicle and the DLR and Esrange receiving stations were aligned to ensure proper telemetry lock, GPS signal, etc. (completed ca. 2130)
 - Created a plan for a first launch attempt for early Wednesday morning, but this is pending some iteration with SSC and the concurrent HADT balloon campaign
 - Issues
 - COVID-19 contact tracing involving other campaign (HADT)
 - This is still somewhat affecting our campaign. There have been about 8 positive cases out of 35 in the balloons and rockets division of SSC, and this has resulted in limited personnel available
 - The main impact is they do not have enough personnel to support simultaneous countdown operations, as we share the launch window with the HADT balloon campaign.
 - DLR is negotiating with SSC for staggered countdown windows to take advantage of good forecasted weather windows so both BOLT and HADT could share the window and both conduct successful flights
 - Plans for Next Day Efforts (**Tuesday 22 June**)
 - Off during the day with an evening report time at 2000
 - A countdown will be initiated at 2100, with nominal end time at 0100 Wednesday. At the end of the countdown the rocket will not be ignited, but a hold will be initiated and the countdown reset to t-minus 20 minutes. Then, weather permitting, at 0140 the countdown will resume to aim for a launch promptly at 0200 Wednesday (this would be 8pm ET in the USA on Tuesday evening!)
 - Outlook/Target Date for Launch via latest meteorological briefings (all launch windows are nominally 0200-1400 LT (0000-1200 UTC) unless otherwise specified)
 - Launch attempt currently planned for 0200 local time Wednesday (0000 UTC). This is 8pm ET Tuesday evening in the USA.
 - Additional Items of Note
 - None

BOLT FLIGHT CAMPAIGN DAY 13: Tuesday 6/22/2021

- Summary
 - Following an evening report time at 2000, the BOLT team photo was taken, followed by the flight readiness review and a practice countdown. A hot countdown was then initiated at 0230 CEST for t-minus 20 minutes.

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- The BOLT flight experiment was launched at 0250 CEST on Wednesday 23 June 2021.