Virtual Research Presentation Conference

Mars Science Helicopter System

Principal Investigator: Teddy Tzanetos (347)
Co-Is: Jon Bapst (322), Gerik Kubiak (347), Havard Grip (343), Luis Phillipe C. Tosi(347), Timothy J. Parker (322), Wayne Johnson (NASA ARC)

Program: Strategic Initiative

Assigned Presentation #RPC-254

Jet Propulsion Laboratory
California Institute of Technology

Beyond Ingenuity

- What comes after Ingenuity?
- What do scientists want to accomplish with a rotorcraft? What is possible?
- Can rotorcraft on Mars carry payloads meaningful to the science community
- Can a rotorcraft larger than Ingenuity fly controllably on Mars ?
- Can a rotorcraft have the autonomy needed to execute science missions objectives?

Why Now

Ingenuity – Mars 2020

- Wright brothers moment for mars in Spring 2021

SOA Technology Demonstration (SOA) vs Science Mission

- Ingenuity: 90s flights, 5 flights, no payload, 10-100m range
- MSH: up to 10min flights, or 2-5-10kg range payloads, or 10km range.

Relevance to NASA and JPL (Impact on current or future programs)

- Build on success and lessons learned from Ingenuity in 2021
- Upcoming 2023 Discovery call for proposals
- Enabling new class of exploration and capabilities

Science

- Submitted whitepaper to
  National Academies Decadal Survey on 8/15
  - 21 authors (12 JPL)
  - 41 cosigners (6 JPL)
- Cross-referenced in 6 other white papers:

1.Bramson, A. M., et al. (2020). Mid-Latitude Ice on Mars: A Science Target for Planetary Climate Histories and an Exploration Target for In Situ Resources.

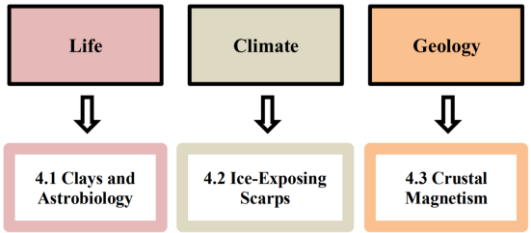
2.Grau Galofre, A., et al. (2020). A Comparative View of Glacial and Periglacial Landforms on Earth and Mars.

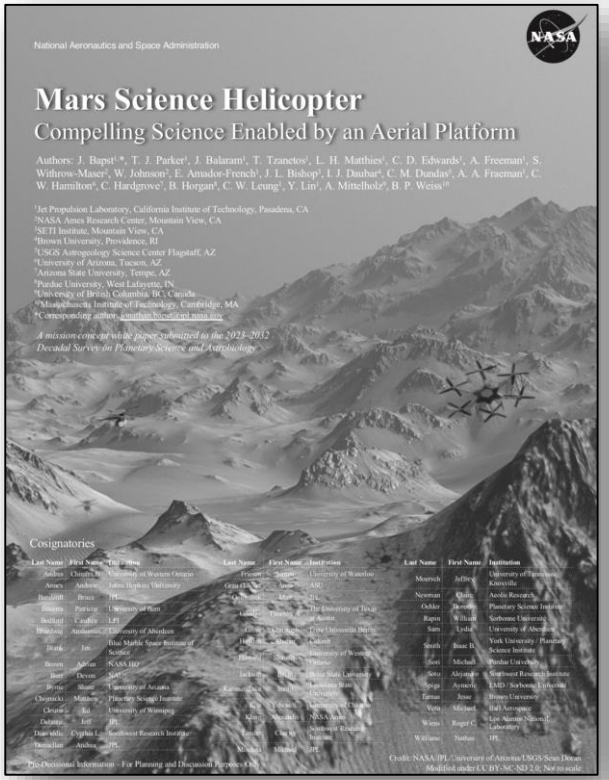
3.Lin, Y., et al. (2020). MASEX - A Dedicated Life Detection Mission on Mars.

4.Mittelholz, A., et al. (2020). Mars' Ancient Dynamo and Crustal Remanent Magnetism.

5.Phillips-Lander, C, et al. (2020). Mars Astrobiological Cave and Internal habitability Explorer (MACIE): A New Frontiers Mission Concept.

6.Rapin, W., et al. (2020). Critical knowledge gaps in the Martian geological record: A rationale for regional-scale in situ exploration by rotorcraft mid-air deployment.




National Aeronautics and Space Administration

Mars Science Helicopter

Compelling Science Enabled by an Aerial Platform

Cosignatories

EMBEDDED PDF→

MSH – Science: Mission Scenario 1 of 3

Ice and Climate at Milanković Crater

Motivation

- What is the relationship between recent climate change and ice ages?
- Where is accessible, near-surface water ice?

Standalone Helicopter

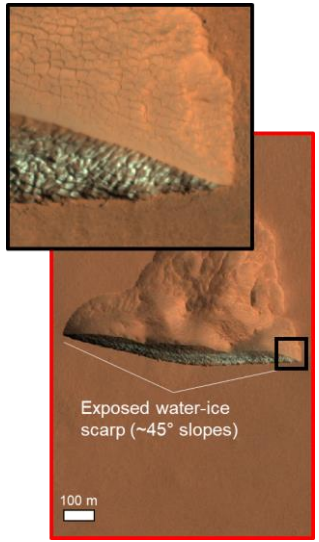
➢ Designed for payload

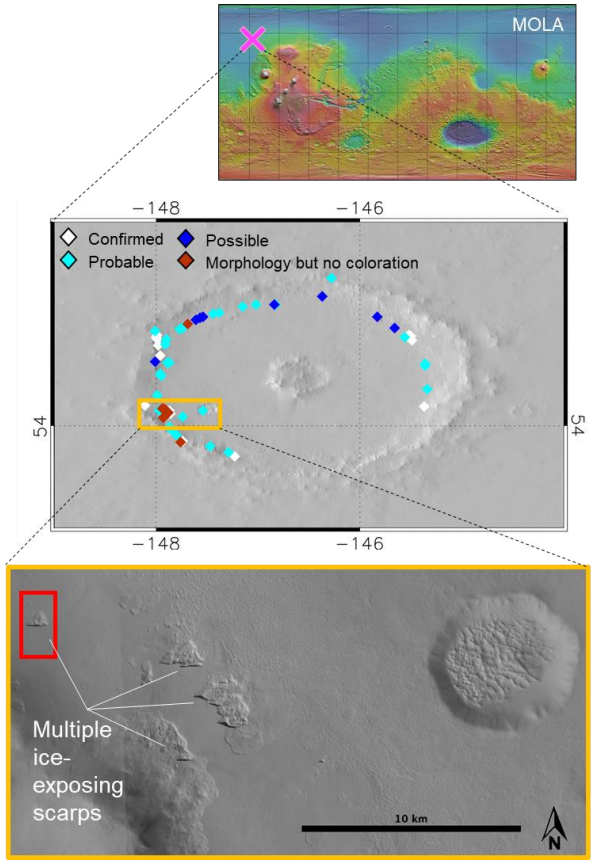
Science Investigations

- Map exposed ice scarp and quantify annual change, if any
- Map distribution and depth of subsurface ice in region
- Characterize local climate (temperature, humidity, and wind velocity)

Instruments

1. Infrared imager (100–200 g)
2. Meteorology package (400–1200 g)
3. Neutron spectrometer (400–500 g)





MSH – Science: Mission Scenario 2 of 3

Paleomagnetism at Newton Basin

Motivation

- How long was the Martian dynamo active, and how did it behave?
- How did the crust of Mars form and evolve during this period?

Standalone Helicopter

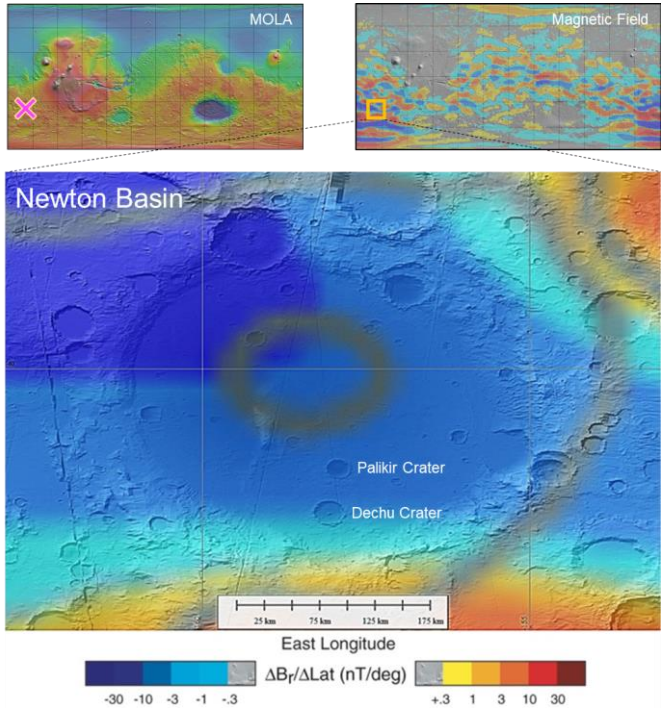
➢ Designed for range

Science Investigations

1. Determine source locations and material compositions of remnant magnetic signatures at high spatial resolution (Langlais et al., 2019)
2. Access, map, and monitor RSLs in numerous craters in basin (e.g., Palikir, Dechu)
3. Access and map valley networks around Newton rim

Instruments

1. VNIR multispectral imager (<500 g)
2. Magnetometer (<100 g + boom/tether)



MSH – Science: Mission Scenario 3 of 3

Organics and Biosignatures at Mawrth Vallis

Motivation

- Are biosignatures present in Martian sediment?
- Is a habitable environment recorded in the geology?

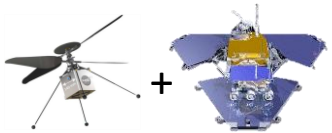
MHTD-style Helicopter
+ Lander Station (e.g., PF)

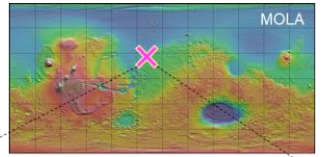
Science Investigations

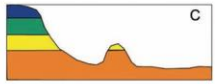
- Sample and analyze chemical/isotopic composition of phyllosilicates and preserved organics

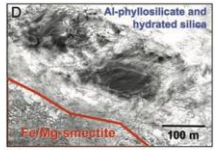
Instruments

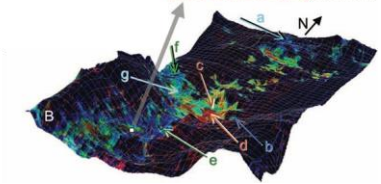
- Helicopter
  1. Sampling arm (~1000+ g)
- Lander (10s of kg)
  1. Gas chromatograph
  2. Mass spectrometer
  3. Raman spectrometer

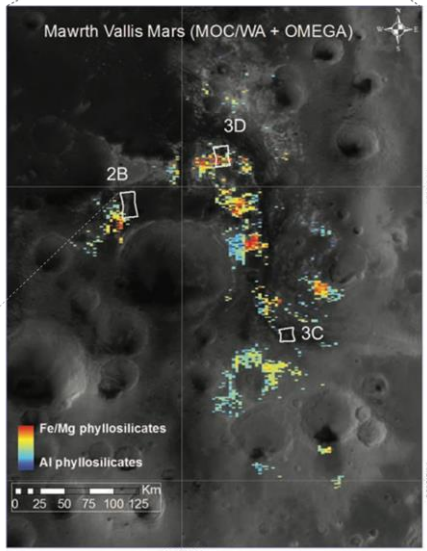










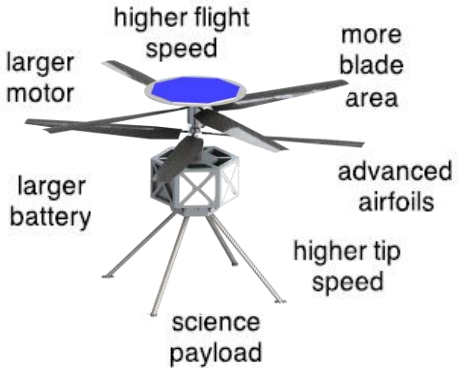


Bishop *et al.*, 2008

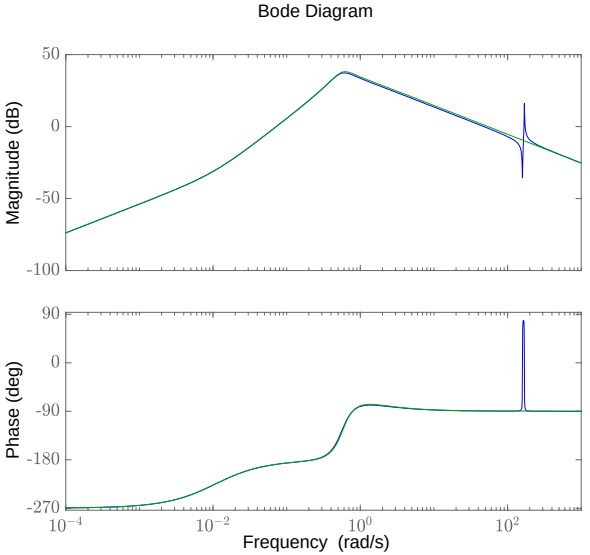
Rotorcraft Design – NASA Ames Research Center

NASA ARC Wayne Johnson and Shannah Withrow

- 3 Designs
  - Hexacopter
  - Scaled Coax
  - Advanced Tech. Demo. Desi
- Aerodynamic Stability



Bode Below: Long input to Pitch response



Vehicle Evolution

Tech Demo Design

1.8 kg

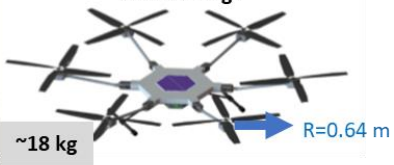
Requires development of control system for hexacopter and managing structural frequencies

Science Helicopter Designs

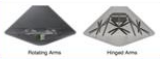
Payload 2 kg;
Range 2 km;
Speed 30 m/s;
Hover 4.5 minutes

HEXACOPTER

Initial Design

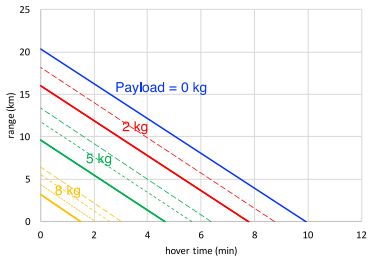


~18 kg



Max Design

~31 kg



COAXIAL HELICOPTER

Initial Design

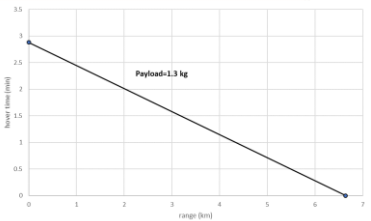
~19 kg

Requires advances in flap damping to overcome stiffness requirements

Advanced Tech Demo Design

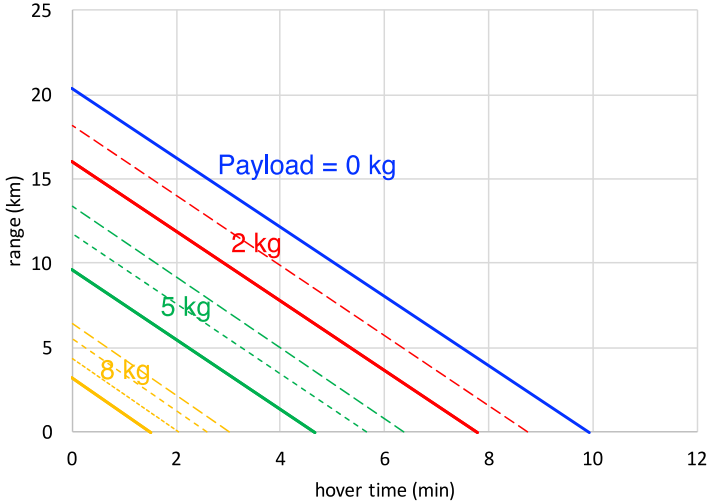
Payload 1.3 kg; Range 2 km; Speed 30 m/s; Hover 2 minutes

4.6 kg

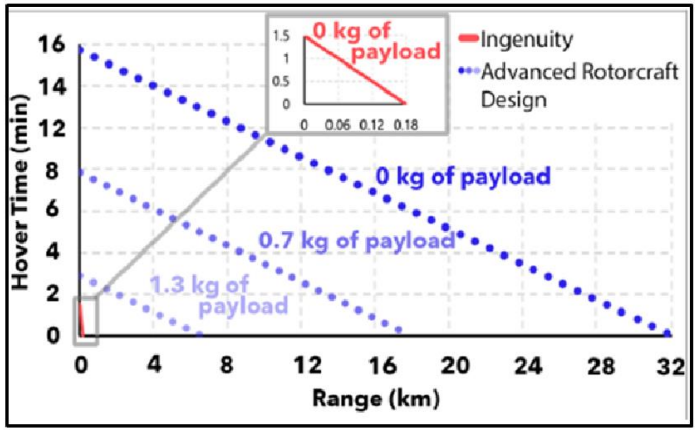


Mission Design Trade Spaces

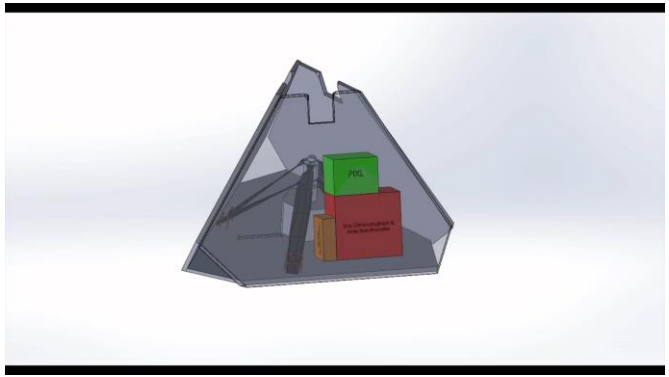
Hexacopter Trade Space

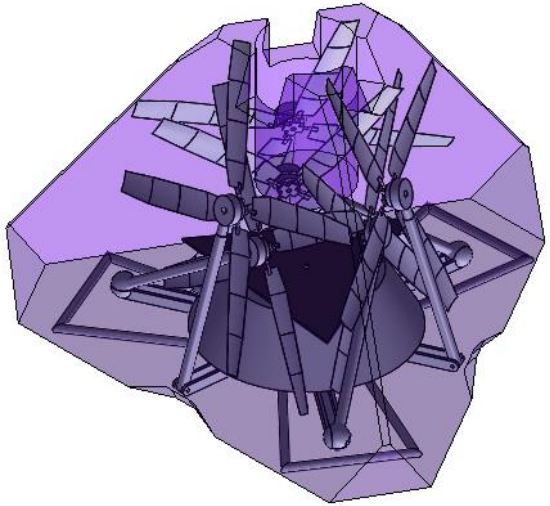


Advanced Tech. Demo Trade Space (Ingenuity Insert)



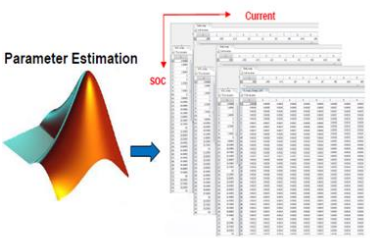
Packaging – Pathfinder Aeroshell

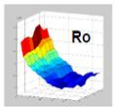


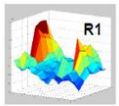


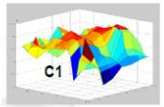
Autonomy, Avionics, Flight-Software(FSW)

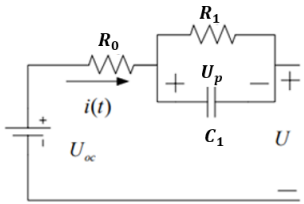
- Fprime FSW
  - Ingenuity Heritage
- Avionics – Big-Little-Style Architecture
  - SWAP Constraints
  - Ingenuity Heritage
  - COTS Snapdragon 820 paired with Microcontrollers
- Mission Management
- Health Management
- Landing Site Detection(LSD) Integrated and Performance V&V (2 Snapdragons)
- Kalman-based Li Battery State of Charge Estimator

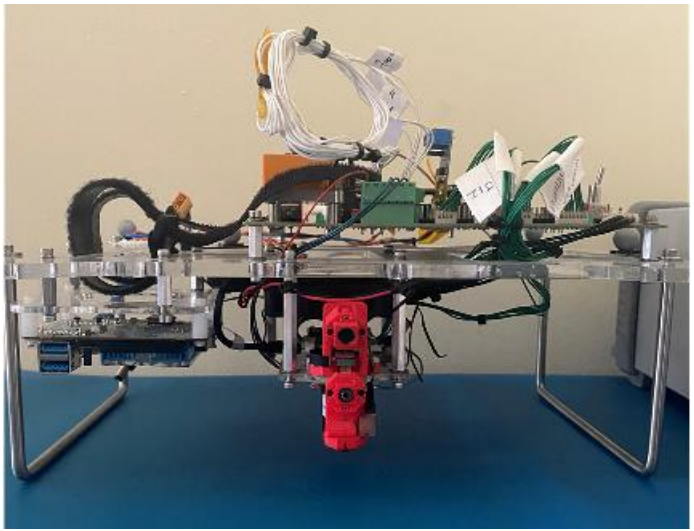












Results

- 2020 Science Decadal Survey Submitted
  - Science Traceability Matrices
- Hexacopter control analysis
- NTR Battery SOC Estimator
- Landing Site Detection(LSD) Integrated
- No Arroyo flight campaign in Q4FY20
  - Smoke/Fire related health restrictions for outdoor activitie
  - COVID-related staffing/quarantines
  - To be flown in Q1Q2FY21
- FY21
  - 2023 Discovery Proposal Team
  - Hexacopter Controllability
  - Global Referencing/Localization GNC Module V&V

Complete

Deprecated early in FY20

Continuing to FY21

Autonomy Deprioritized in Q3/Q4 FY20

Mile-stone	Status	Milestone Title	Summary
1	Complete	Ground Control Station Design	Test flight campaign of FY19 completed most of the GCS design. Small updates needed for Health Monitoring were deprecated
2	Deprecated	Small GNC Quadcopter for Closed Loop Control	Need for a smaller test vehicle diminished in Q1 since closed loop motor control did not become a mobility priority for science capabilities and test flights would not start until Q320
3	Continuing to FY21	NASA Ames + JPL Detailed Controllability assessment of MSH baseline design.	NASA ARC has performed internal controllability assessments. JPL Darts modeling starting FY21. Transfer functions of Hexacopter delivered.
4	SOC Complete	Health monitor, battery state/estimator. SOC	Benchtop tests completed, data analysis underway. I&T with BMC avionics deprecated due to lab access/COVID
5	75% Complete Deprioritized	Navigation-FSW reference frame bridge module. Waypoint creation for demonstrator vehicle. Drift/error monitor and Failover module.	Architecture developed in Fprime, pending field testing. Autonomy deprioritized
6	Deprecated	Demonstrator upgrade for health observability	Health observability of rotorcraft actuators not a priority for this FY
7	Deprecated	Science payload integration, mechanical, electrical, software	Holding off on demonstration payload and selection until science PI is selected for MSH for a specific mission design
8	75% Complete – Deprioritized for FY21	Mission Management (composed of health monitor, mission plan, guidance module)	Architecture defined for mission management and fault scenarios. Needs to be implemented and tested in the field.
9	Complete	Ground Control Station and Toolkit, FPrime GUI + Visualization. Health reporting, mission aborting	Updates to GCS pending for mission management and health monitoring. Mission management and health monitoring deprioritized
10	Deprecated	Simulation for autonomy testing in Helicat, with integration with new MHTD GCS development task.	Tracking Mars Heli Ops tool development to determine where best overlap will be for EOFY flight test campaign.
11	Q1/Q2 Testing in FY21,	Landing Site Detection flight test campaign and analysis	FSW interfaces between ANFMR and MSHS have been defined. Awaiting first delivery end of May of 3D reconstruction. Ready to test.
12(MYR)	Complete	Snapdragon 820 Avionics Flat Sat Rev. B	Avionics Flat Sat. Rev. B board is built, awaiting testing on lab.
13(MYR)	Complete	DARTS Simulation Environment for MSH	DARTS Simulation Environment for MSH complete and being used by ANFMR task. Flying sensor.
14(MYR)	Complete	Decadal Survey Whitepaper Submission	Whitepaper draft in work
15(MYR)	75% Complete Deprioritized	In-Flight Performance Analysis	FSW module defined and being developed. Pending flight test campaign EOFY.

Publications and References

[A] Jon, Baspt, “Mars Science Helicopter: Compelling Science Enabled by an Aerial Platforms” *National Academies Planetary Science and Astrobiology Decadal Survey 2023-2032*

[B] Wayne, Johnson, “Mars Science Helicopter Conceptual Design” NASA/TM—2020–220485, NASA Technical Memo