IRRECONCILABLE DIFFERENCES: FLIGHT OPERATIONS FOR THE M2 SPACECRAFT DIVORCE

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UNSW CANBERRA SPACE MISSIONS



A BIT MORE ABOUT M2: MISSION OBJECTIVES

DIVORCE AND FORMATION STABILISATION PART OF RESEARCH DATA

- Propulsion free formation flying demonstration
 - Collision avoidance manoeuvers
 - Rendezvous and close proximity operations
 - Space surveillance/inspection
- Resident space object (RSO) trajectory change detection
- Technology/on-board processing demonstrations for maritime awareness research
- Technology demonstration for partner organisations



- Conjoined spacecraft begin divorce pointing (aligned with velocity direction).
 - ADCS passive on M2-A, active on M2-B.
 - Reaction wheels switched to passive (holding current speed) immediately prior to separation command.



- Divorce command executes.
 - Burnwire activated.
 - +ΔV applied to M2-A, which **increases** semi-major axis and orbital period.
 - **-ΔV** applied to M2-B, which **decreases** semi-major axis and orbital period.
- ADCS is still passive on M2-A.
- ADCS reaction wheels on M2-B are still holding their speeds.
- 10 images captured with selfie cam on each spacecraft.

TRICKY PART, WILL COME BACK TO THIS



- M2-B passes underneath M2-A and takes the 'lead' position within one orbit of separation (because M2-B orbit now slightly smaller than M2-A orbit).
- ADCS is passive on M2-A.
- ADCS reaction wheels on M2-B are still holding their speeds.



- Mean distance between spacecraft slowly increases because M2-A orbital period > M2-B orbital period.
- Get data to confirm successful separation (solar panel telemetry, GPS data, ground-based sensor observation).
- If separation successful, set ADCS to detumble mode on both spacecraft.



- Deploy solar panels on high-energy spacecraft (M2-A) ASAP.
 - Gradual decrease in semi-major axis and orbital period of M2-A.



 \sim I3 days to deploy first of panels to meet this requirement.



divorce and M2-B panels remain stowed.

M2 DIVORCE AND FORMATION FLYING: STAGE 5

- Monitor mean along-track relative motion.
- Deploy solar panels on low-energy spacecraft (M2-B) when mean along-track relative motion of M2-A and M2-B is ~0.
- Formation stabilised when successful panel deployment confirmed.





motion is ~0.

M2 DIVORCE: SEPARATION ANGLE CONSTRAINTS

- Closest approach > 50 m considered "safe".
- Max separation angle that meets closest approach requirement is 56 deg.
- Max separation angle of 20 deg required to ensure sufficient ΔV in the velocity direction separation.



Distance of closest approach after separation vs alongtrack deviation. Blue circle = 56 deg.

M2 DIVORCE: SEPARATION DATE CONSTRAINTS



Yass ground station pass times for M2 Pathfinder and M2 over the next few months.

M2 DIVORCE: SEPARATION DATE CONSTRAINTS



M2 orbit eclipse duration over course of mission.

M2 DIVORCE: SOMETHINGS THAT MADE IT TRICKY

- Divorce pointing is hard! Reduced ADCS sensor input while spacecraft are joined.
- Reducing time between 'go/no-go' check and physical separation to ensure validity of 'go' criteria.
- Need to avoid triggering FDIR (burnwire burn drops batt V by 0.4 V).
- Sun illumination for photos + GPS availability.
- Uncertain time-syncing between spacecraft.
- Capturing the separation with the selfie-cam:
 - Max 10 photos per spacecraft.
 - Uncertain drift rate after separation.
 - Very uncertain body rate induced by separation springs.

FDIR state	Batt V threshold	Turn off
Nominal	N/A	N/A
Warning	7.45 V	SDR, all payloads
Critical	7.3 V	ADCS, supervisor, eng camera, NSL
EPS cutoff	6.9 V	Spacecraft

M2 DIVORCE: ON-BOARD GO/NO-GO CRITERIA

- Go/no-go automated with new 'safe burnwire enable' command.
- Allows us to minimise time between check and physical separation.
- Retry period and max retries are user specified.

Safety check	Pass criteria
Battery state of charge is sufficient to support the separation sequence.	Battery voltage > configurable value to be refined in SEP- 0.
ADCS is enabled and running the correct firmware version to support the separation sequence.	PDM5 current > configurable value to be refined in SEP-0 and ADCS firmware version \neq 0.
Spacecraft rotation rate is low, indicating that the spacecraft pointing is stable.	Configurable value to be refined in SEP-0 < ADCS rotation rate < configurable value to be refined in SEP-0.
Spacecraft attitude is close to the target attitude.	ADCS attitude error quaternion [0] > configurable value to be refined in SEP-0.
Reaction wheel speeds have successfully been held to prevent further attitude control.	ADCS actuator mode = 0x11.
GPS fix uncertainty is sufficiently low to support research objectives.	GPS position dilution of precision < configurable value to be refined in SEP-0 and \neq 0.
The engineering camera is enabled to support image capture during the separation sequence.	PDM10 current > configurable value to be refined in SEP- 0.

M2 DIVORCE: ON-ORBIT PREPARATION

		Tests conducted in OBC SW V36				
Field	Condition	2021/08/24 12:40:01	2021/08/25 12:35:03	2021/08/29 10:40:03	2021/08/30 10:39:16	2021/08/30 12:10:01
Result: GPS PDOP	N/A	1	1	0	1	1
Result: ADCS attitude error	N/A	0	1	0	1	1
Result: ADCS actuator mode	N/A	1	0	0	0	0
Result: ADCS rotation rate	N/A	0	0	0	0	0
Result: ADCS SW version	N/A	0	0	0	0	0
Result: PDM10 current (camera)	N/A	0	0	1	0	0
Result: PDM5 current (ADCS)	N/A	0	0	0	0	0
Result: Bus battery voltage	N/A	0	0	0	1	0
Burnwire count increase?	N/A	No	No	No	No	No
12V current spike at burnwire time?	N/A	Unconfimed	Unconfirmed	No	No	No

		Tests conducted in OBC SW V41								
Field	Condition	2021/09/02 04:00:03	2021/09/02 05:38:03	2021/09/02 08:48:11	2021/09/02 10:22:03	2021/09/03 03:57:12	2021/09/03 08:46:03	2021/09/03 10:21:03	2021/09/06 01:52:27	2021/09/06 08:28:03
Result: GPS PDOP	N/A	1	1	0	0	0	0	0	1	0
Result: ADCS attitude error	N/A	1	1	0	1	0	1	1	1	1
Result: ADCS actuator mode	N/A	1	1	0	0	0	0	0	1	0
Result: ADCS rotation rate	N/A	1	1	0	0	0	0	0	1	0
Result: ADCS SW version	N/A	1	1	0	0	0	0	0	1	0
Result: PDM10 current (camera)	N/A	0	0	0	0	0	0	0	1	0
Result: PDM5 current (ADCS)	N/A	0	0	0	0	0	0	0	1	0
Result: Bus battery voltage	N/A	0	0	0	0	0	0	1	0	1
Burnwire count increase?	N/A	No	No	Yes	No	Yes	No	No	No	Unconfirmed
12V current spike at burnwire time?	N/A	No	No	Yes	Unconfirmed	Yes	No	No	No	Unconfirmed

Note: M2-A is the passive spacecraft and M2-B is the controlling spacecraft.



M2 DIVORCE: COMMAND UPLINK SEQUENCE / EYESIGHT TEST

M2 DIVORCE: LET'S GO!

It took quite a few tries... but eventually:

Response 1	1777959				< ■ 0
Data Source	YASS-GS		From NORAD ID	411	
Time Received (UTC)	2021-09-10 06:31:15.845		Time Collected (UTC)	2021-09-10 (04:55:12.000
Response Code	0x0155		Response	status_safe	e_burnwire
Decoding Model	M2-MAXIMODEL(20210904T2134	408.945167772)			
		Decoded Fields	Raw HEX Fields		
Filter					Click a row to view or copy the full value.
Field		Descriptio	on		Value
С			indicates whether	is 0	
data_length			s the number of by	on 53	
obc_response_system_time		The syst	em time when the	eted 2021-09-10 04:55:12.0	
ops_id_long		The full	2-byte operations I	0	
obc_safe_bur	nwire_result_gps_pdop	Returns	0 if successful	0	
obc_safe_bur	nwire_result_adcs_attitude_error	Returns	0 if successful	0	
obc_safe_bur	nwire_result_adcs_actuator_mode	Returns	0 if successful	0	
obc_safe_bur	nwire_result_adcs_rotation_rate	Returns	0 if successful	0	
obc_safe_bur	nwire_result_adcs_sw_version	Returns	0 if successful	0	
obc safe burnwire result PDM10 current		Returns	0 if successful	0	
obc_safe_burnwire_result_PDM5_current		Returns	0 if successful	0	
obc_safe_burnwire_result_battery_voltage		Returns	0 if successful	0	
inputBurnwireNum		Burnwire	e ID specified in sa	m 17	
inputSimulationFlag		Simulati	on flag specified in	co 0	
inputRetryPeriod			riod specified in sa	om 1	
inputRetryNumber			specified in safe bu	and. 2	





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CERTIFICATE OF DIVORCE

This is to certify that

<u>M2-A (Alice)</u> and <u>M2-B (Bob)</u> officially ended their marriage on <u>September 10th, 2021 UTC</u> at <u>Low Earth Orbit</u> due to irreconcilable differences.

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ATomachelt

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AFTER THE PAPERWORK CAME THROUGH

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