THIRTY DAYS IN A MOL: BIOMEDICALLY-RELEVANT ASPECTS OF A RECONNAISSANCE MISSION INFERRED FROM ORBITAL PARAMETERS

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Introduction

The Manned Orbiting Laboratory (MOL) Program of the U.S. Air Force is well-known but poorly understood because it was both widely-publicized and largely secret. It was conceived to evaluate the military potential of man in space but quickly evolved to have a dedicated reconnaissance mission. It is of historical interest today for many reasons, not least because of the characteristics of its planned orbit and their possible influence on the physiology and psychology of the men intended to occupy it. But the biomedical aspects of MOL are perhaps the least represented aspects of the available literature.

Early in the MOL program, the Air Force publicized it directly and indirectly through its contractors to gain popular support for its approval. But when the NRO and its camera systems were added, secrecy became the routine as befits such a reconnaissance program. The press augmented occasional public updates with reports based on recycled out-of-date information and occasionally just rumors, conjecture and wishful thinking.[1]

A decade after MOL's cancellation, renewed interest led to new publicity. A large volume of technical detail was declassified and released, but most of it is from the first year or two of the projects development, when MOL was smaller and had a basic and applied research mission to determine the military usefulness of astronauts in spaceflight. This early information was summarized and interpreted in articles in *Spaceflight*[2] in the early 1980s and in *Quest*[3] in the mid-1990s. That information, while voluminous and apparently definitive, was derived from pre-NRO data but presented (in all innocence) as representing the mature MOL planning. One report[4] was apparently based on an interview with a senior military MOL official over a decade after his retirement and presented facts that were, again, consistent with MOL's pre-NRO status; however, it featured photographs of a MOL desktop model that appears to be a highly representative of MOL's mature configuration.

In 1999, the Air Force archives at Maxwell AFB, Alabama, yielded a large volume of early weekly administrative reports and some photographs.[5] Later, an excellent and voluminous analysis of unclassified primary and secondary records concerning MOL and other reconnaissance systems was published by the Air Force[6] in 2005. Interviews and oral histories, albeit hindered by real and imagined secrecy constraints and based on fading memories of events half a century ago, have provided perspectives of individuals who have gone on to more recent—and greater—accomplishments.[7] A documentary television program collected some of those perspectives and some seldom seen footage but provided few new insights.[8]

The Manned Orbiting Laboratory (MOL) Program of the 1960s

The U.S. Air Force announced the MOL program in December 1963 as a 30-ft (10-m) generic space research laboratory. But within the year and a half it took to gain presidential authorization, MOL grew to a 70-ft (21-m) reconnaissance platform with the addition of the DORIAN KH-10 imaging system under the technical control of the secret National Reconnaissance Office (NRO).[9] The involvement of the NRO brought a requirement for near-absolute secrecy whose effects are still felt today.

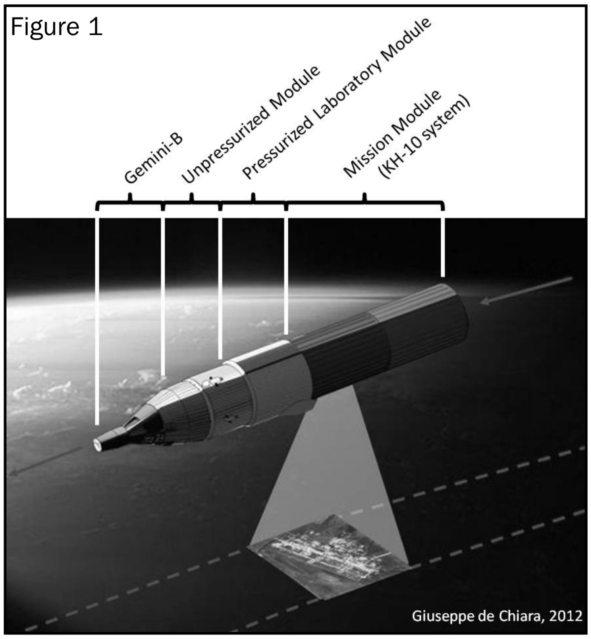
There was discussion of extending the MOL program,[10] but instead it was terminated in 1969 without flying a single mission. Apollo soon overshadowed it in the public eye and the historical record.

The MOL program was baselined for up to five manned missions of two pilots each, at about four month intervals. It would have been ambitious: its baselined duration of 30 days equaled the sum of all human spaceflights—American and Russian—at the time MOL was authorized by President Johnson in August 1965. MOL's biomedical significance would also have derived from its capabilities to document the effects of that duration through onboard measurements and assays.

Weightlessness is a feature of all satellite orbits, but MOL's unprecedented polar orbit would have affected the pilots' activities in ways that might have influenced their physiological and psychological states. Polar orbit was required because of the KH-10: it would allow repeated detailed photographic inspections of sites in northern Russia. This type of orbit would expose the two onboard pilots to unprecedented in-flight radiation while near the poles, as well as preclude ground communication for most of each orbit, demanding unusual autonomy in the preparation and execution of their critical photography tasks.

Apart from its orbit, MOL's vehicle characteristics (Figure 1) would have had biomedical effects. The two pilots on each flight would have occupied a pressurized laboratory module designed around visual reconnaissance using a high-powered camera system

Figure 1



Giuseppe de Chiara, 2012

and associated spotting scopes, but the module would have had only one small porthole.[11] The only other windows would have been in the Gemini-B capsule bolted at the opposite end of the MOL, but it was to be powered down, sealed off and depressurized for the duration of the active mission.[12] The pilots would have worked, exercised, ate and slept for a month in a shared volume of about 400 ft^3 (12 m^3)—about the interior volume of a VW minibus.[13]

In spite of the secrecy, a lot of technical data became available over the decades. The NRO itself has begun declassifying and releasing primary documents from MOL and other orbital reconnaissance programs,[14] many of which have been discussed in *The Space Review.*[15] However, this seemingly definitive content largely comprises isolated briefing charts and pages extracted from larger documents, and is disjointed, ambiguous, contradictory and usually not date-stamped, so substantial interpretation is required. It does, however, contain very little of biomedical relevance.

Given the influence of MOL's orbit on its crewmembers health, any analysis of its significance should begin with the characteristics of that orbit, but available data on its planned orbits are ambiguous and inconsistent. A Freedom of Information Act (FOIA) request in 2013 for launch and orbital information and crew scheduling and other human factors data was approved by the NRO but not provided because the Air Force is responsible for that information; the Air Force has never responded.

In the absence of definitive relevant documentation, we have constructed an orbital model based on known and inferred parameters. We propose a mission scenario, informed by the perspective from several decades of planning and observing operational space missions, that we believe is qualitatively representative of a generic MOL mission of the early 1970s. This scenario can be analyzed for its impact on the duty day, workload and circadian rhythms of the pilots as a foundation for more detailed future assessments of the biomedical aspects of such missions.

Launch to Orbit.

Plans to launch the five piloted MOL missions from Space Launch Complex 6 (SLC-6) at Vandenberg AFB

Table 1. Stipulations for launch to orbit, with justifications and assumptions.

Stipulations		Justifications and Assumptions
Crew wake-up time	4 hr 30 min before launch (T-4:30)	Per NASA Gemini practice.[55]
Launch site	Space Launch Complex-6 (SLC-6), Vandenberg AFB (34.6 N, 120.6 W)	Announced launch site for all polar MOL missions.
Year	1972	NET launch date (approx.) at time of June 1969 MOL cancellation.
Date(s)	21 June; 21 December	Summer solstice for maximum Northern Hemisphere illumination; winter solstice for minimum Northern Hemisphere illumination.
Time of day	20:00 UT, 13:00 PDT (June 21), 12:00 PST (Dec. 21)	Local solar noon, for maximum southbound ground track illumination.
Launch azimuth	188°	Launch azimuth for intended inclination: sin(azimuth) = cos(inclination)/cos(latitude) = cos(96.5°)/cos(35°N).
Initial orbit	Apogee: 186 NM (344 km) Perigee: 80 NM (148 km) Period: 89.28 min (1.488 hr) Inclination: 96.5°	Best available declassified information (NRO release, June 2014). Not circularized by similarity with HEXAGON practice. Perigee not controlled, allowed to drift northward from launch site latitude for convenience of analysis only. "Sun-synchronous."[56]

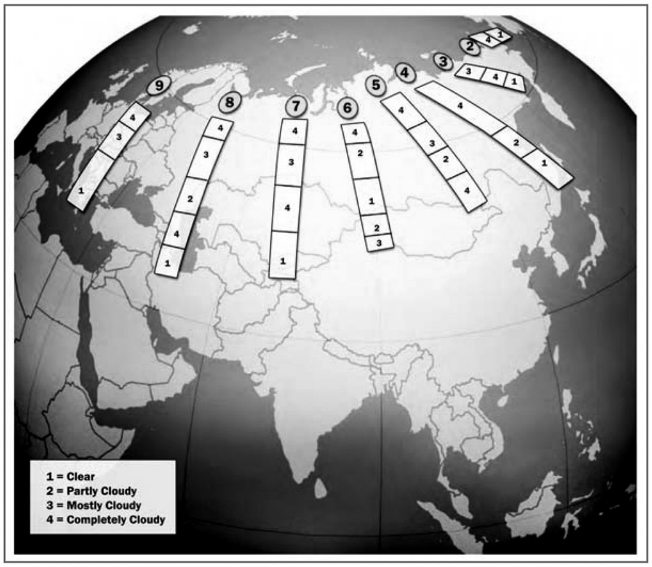


Figure 2. Ground tracks of an early CORONA reconnaissance satellite showing that the targeted imagery was limited to the territory of the USSR and Eastern Europe, and did not include China, Southeast Asia and other land masses that we included in our analysis. (Image from Ref. 34.)

(VAFB)[16] at about four-month intervals [17] confirm there was no preference for the solar illumination conditions of any particular season. Each mission's reconnaissance photography could capture only a single season's lighting within its 30-day duration. We analyzed the modeled mission scenario with a launch date of 21 June 1972, for best-case northern hemisphere seasonal lighting, and 21 December 1972, for worst-case northern hemisphere seasonal lighting.

We chose the year 1972 because that was a predicted launch year in 1969, when MOL planning was mature immediately prior to its cancellation. However, the year would have had little influence on the ground pass illumination factors.

Our choice of launch time of day was arbitrary, unlike in reality when it would have depended on considerations we do not know. Our first attempt at framing a launch time of day was based on a chain of deductions starting with landing time. We hypothesized that there was a preferred local time for Gemini landings, to assure proper lighting at appropriate times in the re-entry, splashdown and recovery process. This was not a farfetched hypothesis: historians have been able to back-calculate early Soviet planned mission durations using the discovery that Soyuz landing times were targeted with respect to local sunrise in the landing area.[18] We hoped to deduce an approximate launch time by hypothesizing that such criteria were also relevant to Gemini missions and that the MOL planners would have used the same criteria to select the Gemini-B landing times for MOL missions, and stipulating that the mission would last 30 days using a reasonable set of orbital parameters.

Comparison of landing times for all Gemini[19] (except *Gemini 8*, which was terminated early after an in-flight emergency) and Earth-orbit Apollo[20] missions (*Apollo 7* and *9* only, not Skylab and Apollo-Soyuz Test Project) showed only that 5 out of 11 landed between three and five hours after local sunrise, and 10 out of 11, between three and nine hours after sunrise. Aside from a preference for the daylight hours, local time was clearly not critical.

Thus, we were free to choose the date and time of day of launch, confident that our results would at least approximate the official planning. Then we calculated lighting over photographic target areas (assuming primary targets would be in the USSR, China, and Southeast Asia, and in Europe and the North America for calibration—much of the entire northern hemisphere).

Therefore, for convenience, we assumed a launch at noon local solar time (13:00 PDT, 20:00 UT) on the day of the summer solstice, 21 June 1972. That date and hour provided nearly maximum solar illumination such that southbound ground tracks in the northern hemisphere, including those over the USSR, would be mainly lit and northbound ground tracks would be mainly dark.

Constraints and assumptions for the launch phase are listed in Table 1.

Orbit

Table 2:
Evolution of perigee location over 30 days for the notional MOL orbit at an inclination of 96.5° for the June 21, 1972, launch date.

Perigee MET dd/hh:mm	Orbit #	Perigee NM	Heading	Lat deg	Dayside (D) or Nightside (N)?
00/01:29	2	80.0	S	55.6 N	D
03/00:59	50	78.9	S	66.1 N	D
06/00:26	98	78.0	S	75.7 N	D
09/01:18	147	77.3	S	83.2 N	D
12/00:37	195	76.9	N	79.2 N	D
14/23:52	243	76.8	N	69.0 N	D
18/00:32	292	76.8	N	58.8 N	N
21/01:07	341	77.0	N	49.4 N	N
24/00:09	389	77.3	N	38.3 N	N
27/00:33	438	77.6	N	27.5 N	N
30/00:49	487	77.7	N	13.0 N	N

We modeled orbital insertion using the Space Shuttle ascent guidance simulator MacMECO. Based on information from the recently declassified MOL documents,[21] we assumed insertion into a sun-synchronous elliptical orbit with a perigee of 80 nautical miles (NM)[22] (148 km) and an apogee of 186 NM (345 km) at an inclination to the equator of 96.5°.

The emphatic assertion by a former MOL pilot that the orbit would have been "sun synchronous"[23] gave us the inclination of 96.5° for our chosen orbital parameters. Range safety constraints at VAFB require a southbound launch azimuth, so we used a launch azimuth of 187.8° (slightly west of south) instead of 352.2° (slight west of north) to achieve the specified inclination.

Our perigee height of 80 NM is lower than some sources[24] have reported for MOL, and is so close to re-entry altitude that it would have required frequent propulsive boosts to remain stable. Our model did not include orbital reboost maneuvers. We also considered a circular orbit at 186 NM, but opted for the elliptical orbit for reasons described below.

MOL was to fly with its attached Gemini-B nose forward in its direction of travel. Its diameter was 10 ft (3.0 m)[25] with four extended pods for the Attitude Control and Translation System (ACTS) around the periphery, so its ballistic area would be about 80 ft^2 (7.4 m^2), and its mass was to be about 30,000 lb (13,600 kg).[26] We used a moderately dense atmosphere model to calculate drag acceleration, which is proportional to the ballistic factor, the ratio of ballistic area to mass. MOL's ballistic factor would have been 0.00267 ft^2/lb (0.00056 m^2/kg).[27] It is reasonable to expect up to (but not much more than) 30 days of MOL orbit lifetime even without subsequent orbit boosts from its ACTS.

Raising perigee height to 186 NM to circularize MOL's orbit would greatly increase orbit lifetime, but would also prevent observing ground targets from very low altitudes on southbound passes over the northern hemisphere. Therefore, we retained the elliptical orbit because (1) the declassified and released NRO documents indicated launch into just such an elliptical orbit, (2) preliminary analysis demonstrated that this orbit would not decay naturally within MOL's 30-day operational period for an object with its ballistic area and mass, and (3) the NRO's KH-9/HEXAGON system,[28] with the same ballistic area and almost as much mass as MOL, flew for 30-60 days in orbits with 80-90 NM perigee and 180 NM apogee, at inclinations of 96-98 degrees[29]—in short, a good reality check

Table 3. Stipulations for in-orbit events, with justifications and assumptions. Target nadir passes (Flight Day 1 only)

Stipulations		Justifications and Assumptions
Initial orbit	Apogee: 186 NM (344 km) Perigee: 80 NM (148 km) Period: 89.3 min (1.49 hr)	• Best available declassified information, ca. Dec. 1968[57] • Not circularized by similarity with HEXAGON practice • Perigee not controlled, allowed to drift northward from launch latitude for convenience of analysis only
Inclination	96.5°	"Sun-synchronous" (Dwayne Day, personal communication).
Orbital operations	Only daytime passes	MOL equipped only for visible observation (radar capability at a later date)
	Only overland passes	Possible ocean surveillance assumed deferred to later date
	Only southbound passes	Northbound passes mostly in darkness due to summer solstice launch date
	Highest priority targets in Eurasia east of Caucasus and Ural Mts.	• Primary targets in USSR, PRC • Secondary targets in Vietnam, Laos, Korea • Tertiary targets in India, Pakistan
	Lower priority targets in Eurasia west of Caucasus Mts., North America	Possible calibration and ground-truth targets in CONUS (including Alaska), Canada, Mexico.
	No targets in Pacific Ocean between California and Siberia	• FD 1 only: post-insertion activities, imaging system activation • All other flight days: time available for ADL, maintenance, medical monitoring • Possible Alaska and ocean targets imaging as needed
	No targets in Atlantic between Spain and Labrador	• Time available for ADL, maintenance, medical monitoring • possible ocean targets imaging as needed
	No other targets except as described above	Assumption to permit evaluation of crewmember duty day
Crew scheduling	Only FD1 analyzed re: times over possible targets	Remaining flight days qualitatively similar to FD1 due to selected orbital features
	Two-shift on-board operations	If required for "lower priority" targets in North America

Table 4. Notional individual FD 1and early FD2 southbound pass start and end times for launch on June 21 and on Dec. 21, 1972.

Coastal crossing event	Orbit #	Flight Day #	21 June 1972 (summer solstice)			21 December 1972 (winter solstice)		
			MET dd/hh:mm	Interval Minutes		MET dd/hh:mm	Interval Minutes	
				Between target passes	During target passes		Between target passes	During target passes
Onto NW Canada coast	2	1	00/01:26	86		00/01:27	87	
Off SE Alaska coast	2	1	00/01:29		3	00/01:29		2
Onto N Alaska coast	3	1	00/02:55	86		00/02:56	87	
Off S Alaska coast	3	1	00/02:59		4	00/02:59		3
Onto E Siberia coast	4	1	00/04:25	86		00/04:26	87	
Off E Siberia coast	4	1	00/04:26		1	00/04:26		0
Onto E Siberia coast	5	1	00/05:54	88		00/05:55	89	
Off S Kamchatka Peninsula	5	1	00/05:59		5	00/05:59		4
Onto E Siberia coast	6	1	00/07:23	84		00/07:25	86	
Off S Korea Peninsula	6	1	00/07:32		9	00/07:32		7
Onto Siberia coast	7	1	00/08:52	80		00/08:54	82	
Off Malay Peninsula	7	1	00/09:09		17	00/09:09		15
Onto W Siberia coast	8	1	00/10:21	72		00/10:24	75	
Off S India coast	8	1	00/10:38		17	00/10:38		14
Onto W Siberia coast	9	1	00/11:51	73		00/11:53	75	
Off S Arabia Peninsula	9	1	00/12:05		14	00/12:05		12
Onto NE Europe coast	10	1	00/13:22	77		00/13:23	78	
Off E Arabia Peninsula	10	1	00/13:32		10	00/13:32		9
Onto Scandinavia Peninsula	11	1	00/14:51	79		00/14:52	80	
Off S Italy coast	11	1	00/14:59		8	00/14:59		7
Onto NE England coast	12	1	00/16:24	85		00/16:24	85	
Off S Spain coast	12	1	00/16:29		5	00/16:29		5
Onto N Labrador coast	15	2	00/20:51	262		00/20:51	262	
Off S Long Island Coast	15	2	00/20:56		5	00/20:56		5
Onto N Canada coast	16	2	00/22:19	83		00/22:19	83	
Off S Mexico coast	16	2	00/22:31		12	00/22:31		12
Onto N Canada coast	17	2	00/23:48	77		00/23:49	78	
Off S California coast	17	2	00/23:57		9	00/23:57		8
Onto NW Canada coast	18	2	01/01:17	80		01/01:18	81	
Off SE Alaska coast	18	2	01/01:21		4	01/01:21		3

for our MOL assessments.

Perigee would initially be near the latitude of launch on lit southbound passes. Consequently, early lit USSR passes would be closer to perigee than to apogee. Perigee was initially at about 56°N and migrated northward, counter to the direction of orbital flight,[30] by 101° over the course of the 30-day mission, northward to the orbit's northernmost limit and then southward on the night side. Thus, perigee would have been over USSR latitudes (41°N to 82°N)[31] during southbound daylight passes for the first nine flight days and during northbound nighttime passes for the next 15 days.[32] In reality, MOL would certainly have used its ACTS to keep perigee over the Eurasian targets of greatest interest to maximize ground resolution, but we did not model such maneuvers.

Evolution of the latitude of perigee as a function of time after launch, or Mission Elapsed Time (MET), is shown in Table 2. MET is presented as "dd/hh:mm" where "dd" is days, "hh" is hours and "mm" is minutes.

Orbit Operations

In order to estimate the duty-day requirements for the MOL pilots, we assumed that high-priority reconnaissance activities would be scheduled only for daylight periods over all of Eurasia east of the Caucasus and Ural Mountains, primarily the USSR, but including China, Vietnam and Korea, as well as Eastern Europe. These ground tracks are longer than CORONA ground tracks (Figure 2) targeting exclusively USSR sites,[33] so our assumption may overestimate the duration of the required crew activity period compared to historical analogous missions. Similar opportunities were also available over North America and Western Europe, if needed for calibration and ground-truth validation purposes. Finally, to simplify our assessment we assumed that MOL employed (1) only visible light photography and not light-independent capabilities such

Table 5. Summary of FD 1 phase durations and intervals during southbound passes after launch on June 21 and Dec. 21, 1972.

Time (minutes)	All Northern Hemisphere targets				High priority targets: Eurasia east of Caucasus Mts.			
	Between passes		Possible target opportunities		Between passes		Possible target opportunities	
	June 21 (summer solstice)	Dec. 21 (winter solstice)	June 21 (summer solstice)	Dec. 21 (winter solstice)	June 21 (summer solstice)	Dec. 21 (winter solstice)	June 21 (summer solstice)	Dec. 21 (winter solstice)
Total	1318	1334	119	103	483	494	63	52
Average	94	95	8	7	81	82	11	9
Maximum	262	262	17	15	88	89	17	15
Minimum	72	75	1	0	72	75	1	0
Median	84	84	8	7	82	84	11	10
Orbit #s (FD 1 only)	All (1-17)				4-9			
MET	00/00:00-00/23:57				00/04:25-00/12:05			

as radar, (2) only overland imaging, and not ocean surveillance, (3) only southbound passes due to the noon launch time, and (4) no targets in the southern hemisphere. All periods during darkness and over the southern hemisphere and the oceans were available for crew activities of daily living (ADL) including sleep, meals, exercise, hygiene, medical monitoring and routine maintenance.

Constraints and assumptions for in-orbit events are listed in Table 3.

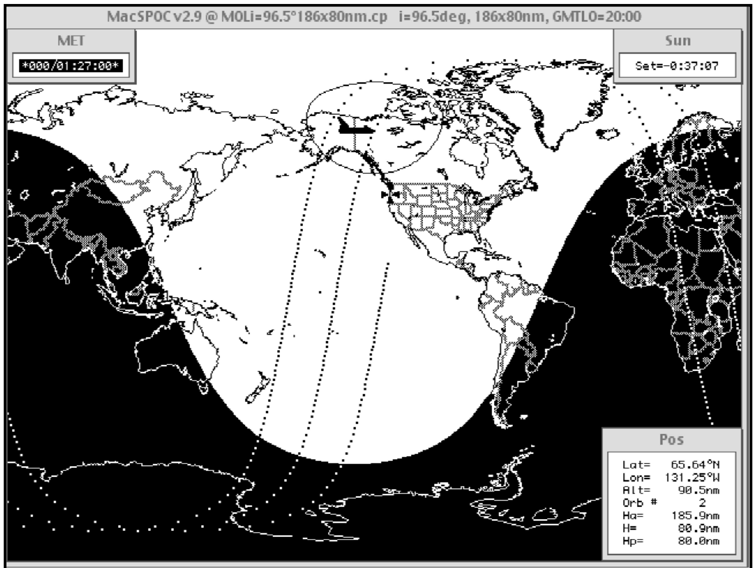
Table 4 lists all of the METs on Flight Day (FD) 1 (the day of launch) for all southbound ground pass start and end times for Eurasia and North America on 21 June (the summer solstice) and 21 December (the winter solstice). The sun-synchronous orbit assured that the lighted southbound passes would be maintained throughout the 30-day mission. Given the solar noon launch time, northernmost Eurasia above the Arctic Circle was illuminated during both southbound and northbound passes after the summer solstice launch, and all pass start and end times correspond to shoreline crossings. The winter solstice launch meant that the Canadian and Eurasian ground pass start times were determined by local sunrise and not coastal crossings, and northernmost land mass imaging would only have been possible on orbits 12-16.

Durations of and intervals between FD 1 southbound passes on 21 June and 21 December 1972, are summarized in Table 5.

The first lighted southbound landfall after launch would have been over the northwest Canadian coast at MET 1 hr 27 min, near the end of the first orbit (Figure 3). The first southbound landfall over Eurasia would have been over eastern Siberia at the start of the fourth orbit, at MET 4 hr 25 min, lasting only one minute. The next six orbits would each have had Eurasian ground tracks lasting 5 to 17 minutes (an average of 11 minutes) at intervals of 75 to 89 minutes (an average of 81 minutes). These are assumed to have been prime imaging orbits. Next would come two orbits over Western Europe and three orbits over the Atlantic Ocean, lasting nearly six hours. Three orbits over North America would complete the first 24 hours in flight. Subsequent days would have followed approximately the same timing.

The northbound/southbound lighting and altitude circumstances persist throughout FD 1 and the remainder of the 30-day mission with only landmass longitude shifting ever westward under the orbit (Figure 4).

Targets above the Arctic Circle would not be illuminat-



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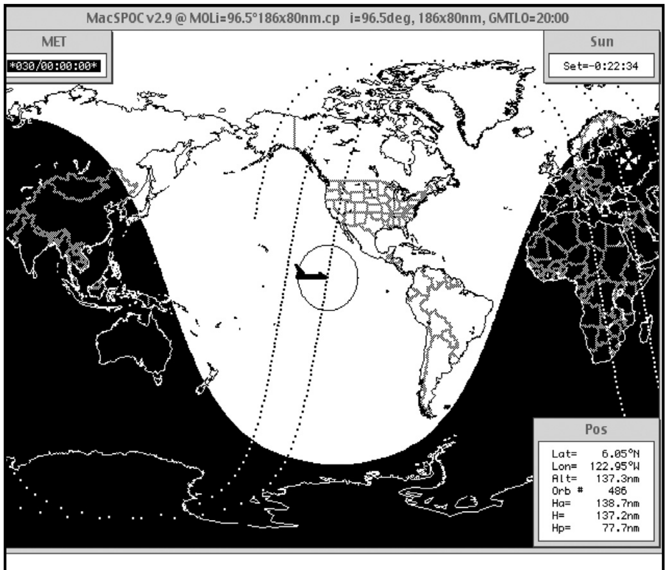
*000/01:27:00*
Set=-0:37:07
Lat=   65.64°N
Lon=  131.25°W
Alt=    90.5nm
Orb #       2
Ha=    185.9nm
H=      80.9nm
Hp=     80.0nm
```

Figure 3. In this notional plot, MOL's location (represented by the Space Shuttle Orbiter silhouette, upper center) is shown at MET 00/01:27 (1.45 hours after launch) at time of good illumination and altitudes near perigee in Orbit 2's southbound leg over northwest Canada.



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*030/00:00:00*
Set=-0:22:34
Lat=    6.05°N
Lon=  122.95°W
Alt=   137.3nm
Orb #     486
Ha=    138.7nm
H=     137.2nm
Hp=     77.7nm
```

Figure 4. By 30 days after launch, a month after the solstice, the notional MOL orbit is more circular and perigee is slightly lower while advancing into the orbit's northbound night side. Due to the sun-synchronous inclination, illumination remains near local noon for mid-northern latitudes on the orbit's southbound leg.

ed at any time (see Figure 5) during the winter MOL mission. However, analysis indicates that the winter solstice launch date, chosen to provide the worst-case lighting conditions over the Northern Hemisphere, would only eliminate the first one to two minutes of each southbound overland pass, and thus would only slightly reduce imaging opportunities.

Our analysis assumes all lighted passes are visually clear. Long-range weather forecasting was a maturing science in the 1960s-1970s, so presumably launch would not have occurred if the chance of cloud cover over Eurasia was predicted to be unacceptably high. Individual imaging orbits would have been scheduled depending on short-term predictions of acceptable weather over the target reconnaissance sites.

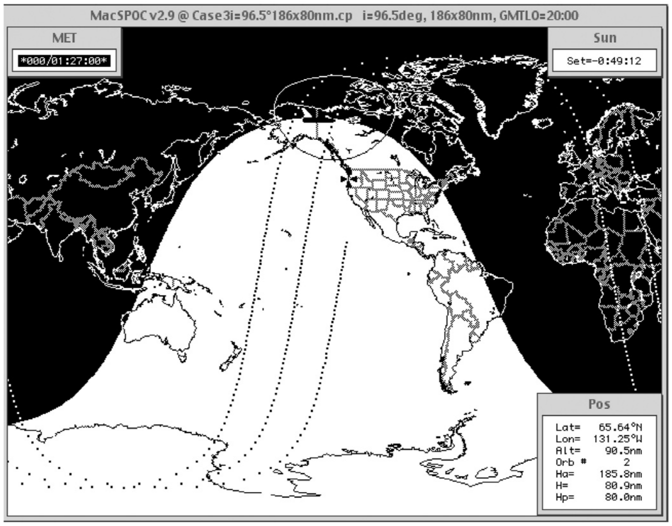
Duty Day

We assumed that the practice for all the Gemini missions was continued such that the MOL pilots were awakened 4½ hours before launch, commencing their duty day. Thus, the set of FD 1 Eurasian overflights would have concluded when the pilots had been awake for nearly 17 hours. Western Europe passes would have occurred during the next three hours. The subsequent North America passes would have lasted up to 28 hours after launch. We do not suggest that the pilots would have been pressed into a full day of imaging duties immediately after launch: MOL activation and checkout and Gemini-B deactivation would probably require most of the first day at minimum. However, the orbit timing would have been repeated on subsequent days, and assuming that the crew awakening time would have been maintained, FD 1 would predict the circadian circumstances for the entire mission.

Crew duty day constraints are not known for the MOL program, but a duty day of 16 hours seems reasonable, based on accepted operational practice. Presumably this would have limited imaging to either Eurasia or North America but not both, unless the pilots were on separate sleep-wake cycles for round-the-clock reconnaissance operations. In fact, this was supported by a statement by a MOL pilot that the crewmen probably would have been on separate shifts.[34]

Table 6:

Activity	Hours/Day per Crewmember		
	MOL (ca. 1964)		ISS (ca. 2006)
Sleep	8		8½
Exercise	1		2½
Meals	1	3½	4½
Hygiene	1		
Leisure	1½		
Station operation	2	9½	6½
Experiments	5½		
Maintenance	2		
Miscellaneous	2		2
Total	**24**		**24**



MacSPOC v2.9 @ Case3i=96.5°186x80nm.cp   i=96.5deg, 186x80nm, GMTLO=20:00

MET *000/01:27:00*

Sun Set=-0:49:12

Pos
Lat= 65.64°N
Lon= 131.25°W
Alt= 90.5nm
Orb # 2
Ha= 185.8nm
H= 80.9nm
Hp= 80.0nm

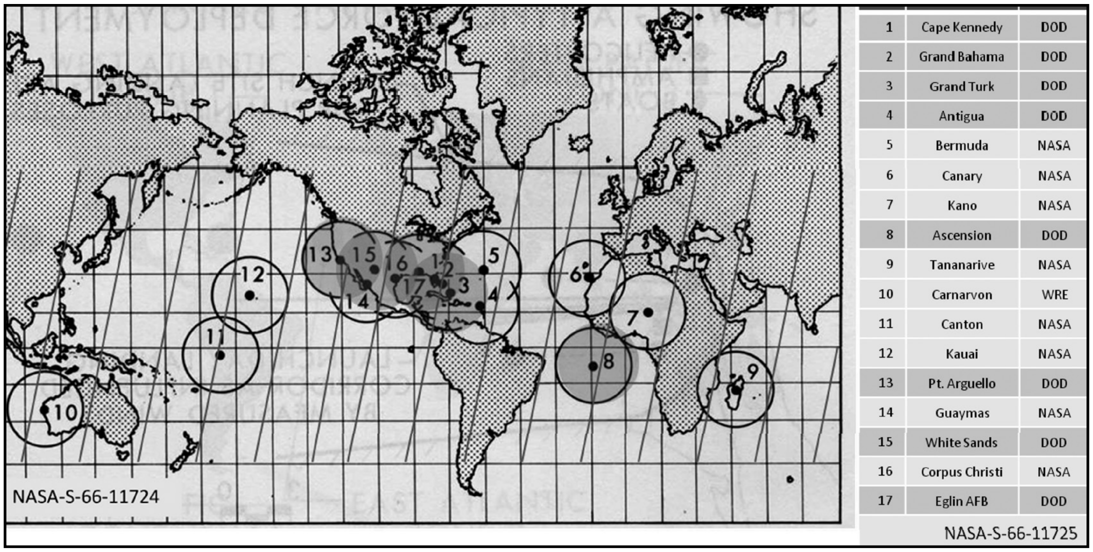
Figure 5. MOL's location is shown at 20:00 UT, or MET 00/01:27 (1.45 hours after launch) on December 21, 1972. This is just as the terminator is crossed on Orbit 2's southbound leg. Because launching near local solar noon places southbound terminator crossings at high northern latitudes, southbound observing passes near the winter solstice aren't appreciably constrained by lighting except for northernmost Eurasia shorelines crossings.

A typical allocation of time for the crewmen[35] is given in Table 6. Its source was apparently a preliminary technical development plan for MOL dated June 1964, very early in the MOL program and in the history of human space flight. It is generic, but it is similar to daily timelines for International Space Station (ISS) astronauts in the 21st century, which are based on decades of spaceflight experience.

The preliminary MOL schedule assigned specific times for specific activities, while the ISS timeline primarily allots longer intervals for a variety of activities to allow the astronauts more flexibility, and thus efficiency, in accomplishing their daily tasks. The MOL schedule clearly discriminated between experiments, station operation and maintenance, while the ISS timeline includes science experiments, preventative and corrective maintenance, visiting vehicle preparations, stowage operations, environment (acoustics, surfaces and water) sampling, public affairs events and miscellaneous medical tasks including daily 2½ hours of exercise.[36] The MOL schedule reflects 1964-era thinking that an astronaut's time in space should be tightly scheduled, based only on experience with one-man Mercury flights lasting no more than 1½ days in which almost every event was time-critical. This attitude moderated over three decades of US and Russian operational experience, including the so-called "Skylab mutiny" against just such micromanagement.[37]

Note that the ISS schedule specifically allots three more hours per day than MOL did for ADL, while MOL allocated those extra hours to station operations, experiments and maintenance. This also reflects a conservative MOL approach naïve of the efficiency and productivity of providing adequate time to the astronauts for the necessities of life.

We estimated that 9 hrs 6 mins would have been



1	Cape Kennedy	DOD
2	Grand Bahama	DOD
3	Grand Turk	DOD
4	Antigua	DOD
5	Bermuda	NASA
6	Canary	NASA
7	Kano	NASA
8	Ascension	DOD
9	Tananarive	NASA
10	Carnarvon	WRE
11	Canton	NASA
12	Kauai	NASA
13	Pt. Arguello	DOD
14	Guaymas	NASA
15	White Sands	DOD
16	Corpus Christi	NASA
17	Eglin AFB	DOD

NASA-S-66-11725

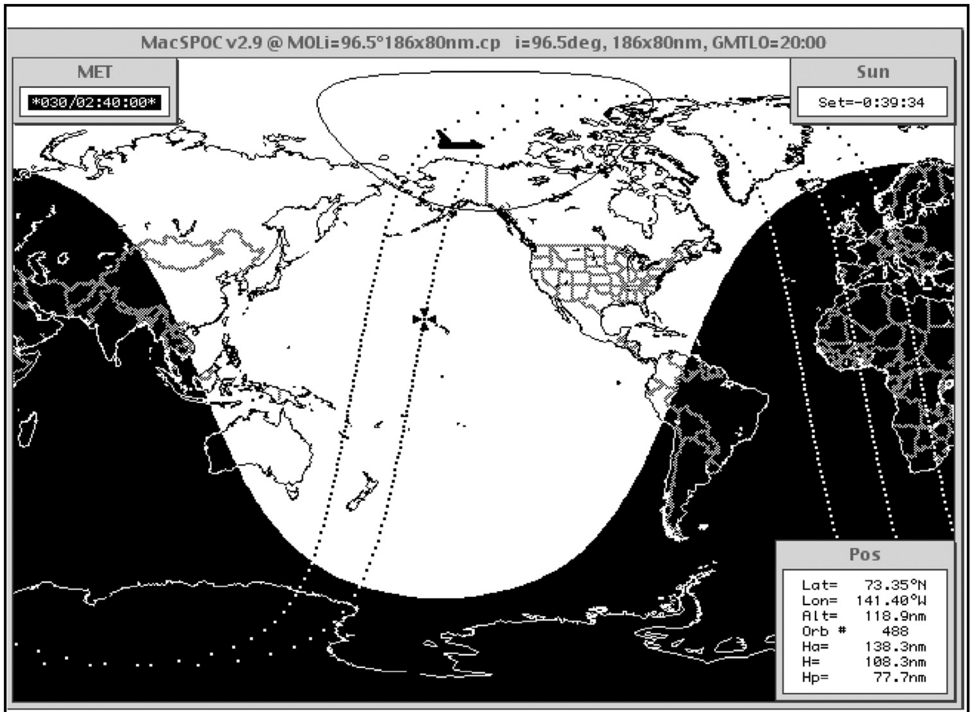
Figure 6: These notional daylight MOL partial ground tracks (each proceeding from north-northeast to south-southwest) illustrate the limited opportunities for communications using Gemini ground stations[39] including both DoD (shaded) and NASA facilities. Carnarvon (#10) would probably not have been available for military use. This image does not include possible tracking ships and aircraft. (Image and data from Ref. 39, modified by the authors)

required for a complete series of high priority eastern Eurasian passes, which is consistent with the early MOL allocation of 9½ hours for mission activities. However, we estimated only 1 hr 3 mins would be required for all possible observing opportunities, leaving 8 hrs 3 mins distributed across 6 orbits for non-observation activities such as station operation, maintenance, and the inevitable documentation of completed observations and preparations for upcoming passes.

Secretary of Defense Robert Macnamara noted that the main reason to proceed with the MOL "was to obtain information quickly and on a selective basis...this would require the manned system...[38] Thus, mission objectives might not have required exercising every single observation opportunity, especially those already acquired in which no changes were expected. In these ways, crew time could have been reallocated to other necessary activities.

Separate shifts might have been scheduled for the crewmen such that one was responsible for prime target photography over Eurasia and the other was responsible for secondary ground-truth photography and for communications with ground stations (described below) over the US. Such alternate shifts would have complicated living in the confined MOL cabin, as when one pilot was sleeping while the other was operating the cameras and tape recorders. It appears that the pilots would have slept in sleeping bags hung in the cabin, not in soundproof "sleep pods" shown in some early MOL photos and similar to those later adopted for Space Shuttle use. Vigorous off-duty activities such as exercise would not have been scheduled during photography sessions requiring a stable vehicle to avoid camera jitter. Then there is the possibility of "sleep shifting" when one pilot sleeps and wakes up earlier for the North American shift and the other does the opposite for the Eurasian shift; both then would have needed to realign their schedules before landing.

Possibly such human factors issues would simply have been tolerated by the military planners and pilots of MOL as unpleasant necessities for these highly-constrained missions.


MacSPOC v2.9 @ MOLi=96.5°186x80nm.cp   i=96.5deg, 186x80nm, GMTLO=20:00

MET
030/02:40:00

Sun
Set=-0:39:34

Pos
```
Lat=     73.35°N
Lon=    141.40°W
Alt=     118.9nm
Orb #      488
Ha=      138.3nm
H=       108.3nm
Hp=       77.7nm
```

Figure 7. We notionally targeted Gemini-B for splashdown near Hawaii (see iron cross symbol) on Orbit 488 after retrofire north of Spain. Terminal guidance and control would presumably be provided by a tracking station, ship or aircraft in the North Atlantic north of Spain.

Communications

The MOL pilots would have had greater inflight autonomy in planning their reconnaissance target photography passes than any of their American predecessors because their opportunities to communicate with ground controllers would have been much more limited. Specifically, the lack of AOS through ground stations during and immediately before any southbound daylight passes over the USSR and China would have required autonomous on-board planning and real-time target selection.

Existing NASA and DoD ground stations used for NASA's Gemini flights were in a belt within about 30° of the equator, mostly over the southern US and the eastern Atlantic Ocean[39] (see Figure 6). Thus, in its polar orbit, MOL would be traveling roughly perpendicular to that belt and would pass through only one or two communications stations' footprints on any orbits, southbound during western hemisphere daylight passes and northbound during nighttime passes. These passes would have afforded about 10 minutes or less for communications (acquisition of signal, AOS) separated by nearly 80 minutes of radio silence. Six orbits each day (southbound and later northbound over the western Pacific and Indian Ocean) would have not permitted any contact at all. Furthermore, any requirement to use only the DoD stations for these military missions would have restricted AOS to seven orbits each day crossing the continental US and the eastern Atlantic Ocean. For example, Carnarvon in western Australia was not available for use during DoD Shuttle missions, and probably would have been excluded from the MOL options.

Our analysis does not include tracking ships or specially-equipped aircraft which might have been deployed in remote areas, as was routinely done during other spaceflight programs, especially in the orbit leading up to the deorbit maneuvers.

Radiation

An important biomedical aspect of MOL missions in polar orbits would have been the radiation exposure of the pilots. In low altitude, low inclination orbits as flown by NASA's Gemini missions, the main source of radiation was trapped protons in the South Atlantic Anomaly (SAA), with a much smaller proportion coming from galactic cosmic radiation (GCR). The longest Gemini missions recorded the highest radiation doses in low earth orbit: the 8-day, 200 NM (370 km) *Gemini V* acquired 140-195 mrad (across 3 locations on 2 crewmen), and the 14-day, 160 NM (300 km) *Gemini VII*, 105-231 mrad.[40] These values correspond to approximately 100-230 mrem.[41] Extrapolated to 30 days, they would be between 200 and 500 mrem.

In a polar orbit, the dose due to the SAA decreases somewhat and the GCR dose increases by about 40% due to less geomagnetic shielding while traversing the high latitudes. The total dose to the blood-forming organs would be about 25% less than in a near-equatorial orbit.[42] There is considerable uncertainty in these estimated doses, which would be only half of the dose of a clinical abdominal x-ray.[43]

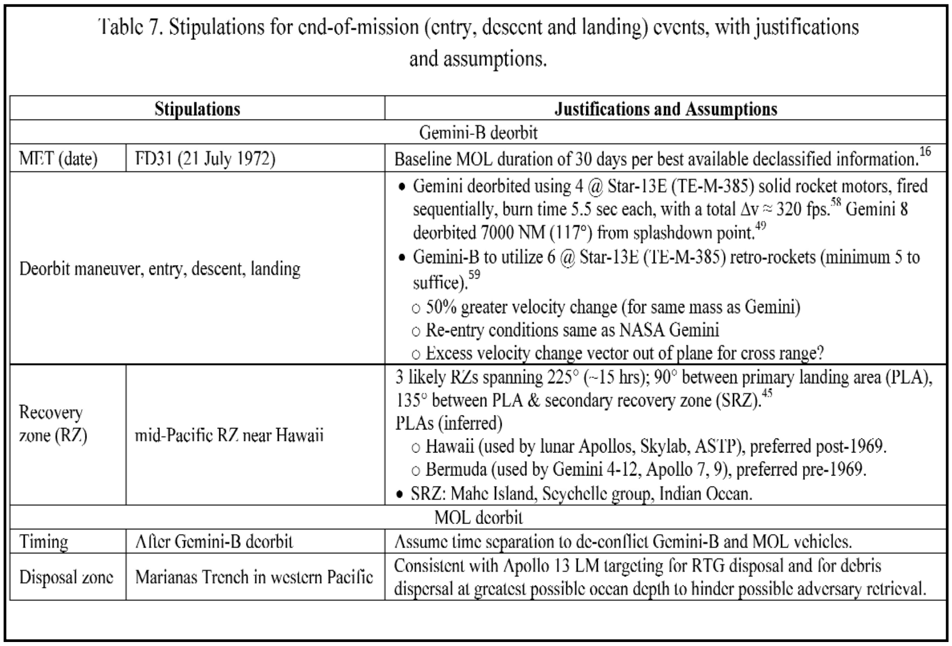


Table 7. Stipulations for end-of-mission (entry, descent and landing) events, with justifications and assumptions.

Stipulations		Justifications and Assumptions
Gemini-B deorbit		
MET (date)	FD31 (21 July 1972)	Baseline MOL duration of 30 days per best available declassified information.[16]
Deorbit maneuver, entry, descent, landing		• Gemini deorbited using 4 @ Star-13E (TE-M-385) solid rocket motors, fired sequentially, burn time 5.5 sec each, with a total $\Delta v \approx 320$ fps.[58] Gemini 8 deorbited 7000 NM (117°) from splashdown point.[49] • Gemini-B to utilize 6 @ Star-13E (TE-M-385) retro-rockets (minimum 5 to suffice).[59] ○ 50% greater velocity change (for same mass as Gemini) ○ Re-entry conditions same as NASA Gemini ○ Excess velocity change vector out of plane for cross range?
Recovery zone (RZ)	mid-Pacific RZ near Hawaii	3 likely RZs spanning 225° (~15 hrs); 90° between primary landing area (PLA), 135° between PLA & secondary recovery zone (SRZ).[45] PLAs (inferred) ○ Hawaii (used by lunar Apollos, Skylab, ASTP), preferred post-1969. ○ Bermuda (used by Gemini 4-12, Apollo 7, 9), preferred pre-1969. • SRZ: Mahe Island, Seychelle group, Indian Ocean.
MOL deorbit		
Timing	After Gemini-B deorbit	Assume time separation to de-conflict Gemini-B and MOL vehicles.
Disposal zone	Marianas Trench in western Pacific	Consistent with Apollo 13 LM targeting for RTG disposal and for debris dispersal at greatest possible ocean depth to hinder possible adversary retrieval.

End of Mission

The end-of-mission location would have biomedical significance through its effect on the crew duty day and the physical and psychological loads of the reentry and landing process.

A trade journal[44] inferred locations of the three landing areas for MOL missions based on published Congressional testimony: two primary zones about 90° (thus, about 15 hours of orbital flight) apart, near Hawaii (which we estimated as 20°N, 158°W) and Bermuda (estimated as 32°N, 65°W), and a secondary zone about 135° from each of them near Mahe Island, Seychelles group, Indian Ocean (estimated as 5°S, 55°E).

The two primary MOL recovery zones were already part of the larger group of Gemini recovery zones.[45] We reviewed Gemini and Apollo (earth-orbital missions only) splashdown locations[46] to identify any demonstrated preference among them by the DOD for MOL recovery. All but two manned Gemini flights (*Gemini III* and *VIII*) landed in the western Atlantic recovery zone near Bermuda, suggesting that it might also have been preferred for MOL's Gemini-B splashdown. However, all the subsequent lunar Apollo missions plus Skylab and ASTP capsules landed in the central Pacific near Hawaii.[47] In addition, unmanned spy satellite capsules were routinely recovered near Hawaii . Therefore, our mission reconstruction assumed Hawaii was the preferred location for MOL recovery in the mid-1970s when MOL would have been flying (see Figure 7).

The Gemini-B spacecraft was to have only a 14-hour capacity for independent flight after separation from the MOL, adequate for a single progression through all of the prime and alternate landing sites if conditions demanded, suggesting that the pilots would have remained in the MOL until weather predictions were optimal for landing at at least one recovery zone.

Details of Gemini-B entry, descent and landing profile are not known, but to end near Hawaii in the sun-synchronous orbit analyzed here, NASA's standard Gemini vehicles would have fired their four retrorockets approximately 1/3 of an orbit earlier,[48] during the northbound night portion of Orbit 487 just off the northwestern corner of Spain.

Gemini-B was to have six of the same retrorockets[59] as NASA's Gemini, which would have provided a 50% greater change in velocity (delta velocity or Δv). They were provided to assure a safe launch pad abort if the Titan IIIM booster exploded before or shortly after launch.[49] It has been posited[50] that Gemini-B would need more retrorockets because it was to fly in a higher orbit than Gemini,[51] but the evidence is that its orbit would not have been higher, and in fact probably even lower; furthermore, the excess retrorocket capability would only have been appropriate for a much higher orbit beyond any usefulness for high resolution earth reconnaissance.

Nor is there evidence of planning for a shorter arc from deorbit to atmospheric entry resulting in a steeper atmospheric entry with higher deceleration g loading and thermal loads than the preceding Gemini flights. The Gemini-B heat shield, including the crew transfer hatch, was flight qualified in a reentry test that provided the same heat loads and profile as the corresponding test for the standard Gemini spacecraft.[52]

It is possible that, if Gemini-B was intended to use all six retrorockets in a routine deorbiting,[53] the excess thrust could have been directed out-of-plane to maneuver the reentry module further to the left or right of its ground track than Gemini's limited aerodynamic capabilities[54] would have permitted. Perhaps all nominal deorbitings would routinely target the excess thrust out-of-plane, so planning for landings would have included appropriate compensation. That, however, is only speculation at this time.

The relative timing of the MOL itself deorbiting after departure of the Gemini-B does not have any biomedical significance beyond insuring adequate in-flight separation to deconflict their terminal guidance and control by ground stations.

Constraints and assumptions for end-of-mission events are listed in Table 7.

Biomedical Aspects of MOL Not Related to Its Polar Orbit.

MOL presented both a requirement and an opportunity for detailed medical measurements and assessments to assure continued crew fitness for duty during each month-long flight and in the face of the physiological stress during and after re-entry and splashdown. Even after its mission was refocused in 1965 and its program of scientific investigations was cancelled, MOL stimulated the development of the technology to measure body weight in a weightless environment as a way to assess crewmembers' health status, exercise and cardiovascular interventions against the deconditioning of weightlessness, and food storage and delivery systems to provide the metabolic substrate for the health and performance necessary to accomplish the challenging tasks envisioned for MOL. Specific details of these orbit-independent topics are outside the scope of this work.

Conclusions

Despite never having flown a single mission, MOL contributed to the foundation of space medicine by stimulating the planning that would be fundamental to future long-duration and autonomous space missions.

Recent years have seen more frequent declassification of MOL data, but little of it is directly relevant to human factors involved in executing such flights. We have attempted to provide some of the missing context through novel analyses of existing information. In particular, the basic characteristics of MOL's planned orbit during its 30-day reconnaissance mission may be indifferent to the quantity and quality of extant information. Our analysis is not exhaustive or conclusive but it provides a foundation for future reconstructions as well as provides context for new data when they become available.

Acknowledgements

The authors thank Dr. Dwayne Day for his generosity in providing access to the available documentation on MOL, and Ms. Laurie Abadie for helpful discussions on orbital mechanics and mission planning.

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