BELLCOMM, INC.

SUBJECT: Astronaut and System Performance During Gemini EVA - Case 340

DATE: November 1, 1966

FROM: D.B. Hoffman
A.N. Kontaratos

ABSTRACT

Results of the Gemini EVA program have suggested that man's functional performance in weightlessness may be severely limited. In this paper, the available physiological data are analyzed, and discussed in the light of environmental and systems constraints. This analysis revealed that the unrestrained astronaut had to work harder to perform the same task in a weightless environment than on earth. However, the heat exchange capacity of the Gemini space suit system can be overloaded at heat outputs equivalent to those produced by a man in a pressurized space suit walking at only one mile per hour, therefore almost assuring saturation during EVA. Recommendations are made which, if implemented, should increase man's efficiency and utility during future EVA.

BELLCOMM, INC.

SUBJECT: Astronaut and System Performance During Gemini EVA - Case 340

DATE: November 1, 1966

FROM: D. B. Hoffman
A. N. Kontaratos

MEMORANDUM FOR FILE

INTRODUCTION

The importance of EVA for the future of manned space flight needs little elaboration. Yet two of the four EVA attempts by U.S. astronauts were ended prematurely because of conditions which became physically intolerable. Available physiological data from the other two U.S. space walks and the single U.S.S.R. trial have indicated that life under these circumstances was, at least, strenuous. Since the physiological response of the astronaut during EVA relates to his operational efficiency, special attention must be devoted to understanding the causes of the Gemini difficulties.*

In view of the more than 2000 hours combined U.S. and U.S.S.R. orbital experience, the difficulties encountered during EVA should not be considered to be the result of some intrinsic intolerability of life to space flight. The explanation must be sought instead in limitations existing in the space suit system, the operational procedures, the mission planning, or the earth based simulation either individually or collectively.

The purpose of this memorandum is to attempt to analyze the problem and to recommend remedial measures.

RESULTS OF PHYSIOLOGICAL INVESTIGATIONS

The physiological data obtained during EVA which are available to us are summarized in Table I. Of special interest are the high sustained heart rates, ventilation rates and the physical sensations (fatigue, sweating, etc.) experienced in all EVA trials. These manifestations, as explained below, appear to be attributable to a combined mechanical and thermal stress (high work load plus limited capability of the EVA life support system to remove heat and water) upon which is probably superimposed an emotional component.

---

*MSC is presently preparing a position paper on extravehicular activity (EVA).

[redacted]

The inflated space suit impairs performance and adds to the metabolic expenditure during the performance of normal tasks. This is due to physical interference, limited bending capability of the thigh and knee regions, rigidity of the waist, and to the effort to overcome the suit resistance to flexure caused by the differential gas pressure.* As a result, even the mere bending of the extremities and the maintenance of such posture can be strenuous. For example, a great deal of physical effort was required by Gordon to keep his legs gripping the Agena for tethering operations during the Gemini 11 flight.

As seen in Table II, the rate of heat production, a measure of physiological effort, is greatly increased when a pressurized space suit is worn during an operation as compared to the rate obtained during the same operation with the subject unsuited. For example, during normally mild exercise (0.8 mph on a treadmill), the presence of the inflated Gemini space suit would have required the equivalent of about 84 percent of the total working capacity of the EVA life support system (1400 BTU/hr nominal, and 2000 BTU/hr for periods of short duration)**. Under conditions of more strenuous exercise, its nominal working capacity would have been exceeded.

As reported by the astronauts, the work load required during EVA was fairly strenuous, and earth based simulations failed to provide them with the necessary experience. The unrestrained astronaut not only can no longer utilize his body weight for mechanical advantage during task performance in weightlessness, but he also experiences forces of reaction which make him lose his dynamic stability. Continual striving to maintain his body position during task performance further increases his energy expenditure.*** Thus, the inherent limitations of the space suit system plus the lack of adequate provisions of restraint (handholds, footholds, harnesses, positioning devices, etc.) are responsible for increasing the amount of work required for effective performance in weightlessness. In addition strenuous and lengthy pre-EVA preparations could accelerate the onset of the observed physiological manifestations. Astronaut Gordon, for example, noted that he was tired even before he left the spacecraft.

In the particular case of GT-9, the ELSS (Extravehicular Life Support System) evaporator/condenser could not keep pace

---

*Current Apollo space suit configurations are anticipated to reduce this problem. Pertinent investigation is currently underway at MSC.

**Presently MSC is evaluating the thermal characteristics of the Apollo backpack. Tests completed indicate a capability for handling a nominal thermal load of 1600 BTU/hr for 3 hrs and thermal transients between 3,000 to 4,000 BTU/hr for several minutes.

***This effect is not expected to be present during the Apollo lunar EVA since the required stability will probably be provided by lunar gravity.

with the thermal load and prevent fogging of the space suit visor.* Furthermore fogging was probably enhanced by the high respiration rates observed during EVA. This breath rate could have saturated the greater part of the total oxygen flow to the helment, simultaneously accelerating the condensation process to allow fogging at normal visor operating temperatures and also inhibit clearing of the visor.**

In the particular case of GT-11, overexertion apparently caused overloading of the EVA life support system. This could have led to the observed functional degradation (fatigue and vision impairment caused by excessive sweating), necessitating early abort of the EVA phase.

Finally, one must also consider the possibility of a number of miscellaneous factors which could have contributed to the observed difficulties, namely:

1. The addition of the chestpack adds to the physical interference problem during EVA.

2. High motivation could obscure the perception of discomfort and impending stress.

3. Emotions as a rule worsen the physiological manifestations and therefore could place additional demands on the space suit system.

4. The pulmonary oxygen partial pressure of the astronaut during EVA could drop to a subnormal level in the event of a buildup in H_2O vapor pressure and CO_2.***

   The combination of a low oxygen partial pressure and an enhanced ambient CO_2 can increase pulse and respiration rates, decrease the physiological reserves for muscular activity and lead to premature exhaustion. Hyperventilation itself can also lead to similar physiological responses and performance decrements through progressive pulmonary CO_2 depletion.

---

*There is evidence indicating that the evaporator/condenser performance was degraded due to dryout occurring sometime during the mission, presumably at or near the time of ingress. Dryout is attributable to higher than anticipated metabolic load.

**The use of an anti-fog compound has eliminated the fogging problem as evidenced in GT-11. However, the physical bases for its origin are still present.

***For this reason the total pressure provided by the Apollo backpack has been increased recently to 3.9 ± 0.1 psi

5. Russian data indicate that moderate physical activity during space flight can cause high pulse rates, sweating and early fatigue. According to Russian physiologists (Gazenko et al.) these observations suggest shifts in the regulation and dynamics of the circulatory system that could affect performance. However, physiological reactions to mild exercise in Gemini missions have failed to produce similar effects.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the poor performance of the Gemini astronauts in EVA is readily explained by the combinations of a life support system with low work load margins, the restraint from the inflated suit, and an unexpectedly strenuous work load due to zero G effects. Other factors - high motivation, emotions, oxygen partial pressure, hyperventilation response and cardiovascular shifts - may also be involved but are not considered to be of primary importance. With a view to insuring effective EVA operations for Apollo and AAP, the following recommendations are made:

1. Those of the "other factors" that could be checked by ground simulation at high work load should be so studied if such an effort is not underway. The first reasonable opportunity for flight test would appear to be the S-IVB work shop (AS-209 and subsequent rendezvous). No great urgency is seen for earlier flight. The proposed experiment payloads should be reviewed for coverage of these factors.

2. Work load margins for space suit - life support systems must be reevaluated. The relative flexibility of the Apollo Block II suit may well offer adequate margin for 1/6 G operation; current MSC studies should press for high work load simulations.

3. If possible, additional EVA exercises over and above GT-12 should be performed before the lunar landing to provide operational experience and demonstrate the adequacy of the Apollo space suit system.

4. A backpack with nominal and transient thermal characteristics adequate to accommodate the functional work capacity of a typical astronaut should be considered for AAP.

5. It should be recognized that zero gravity activities are novel and require both study by the engineer and learning by the astronaut.

   a. A variety of means to give the astronaut stability and leverage (handholds, harnesses, footholds, etc.) must be tried to find which are most efficient. This should begin on Gemini 12 and continue (even intravehicularly on early Apollo flights) as necessary to support off-nominal missions (e.g., extravehicular crew transfer). It should be a major effort in the AAP.

b. EVA operation procedures should be rescheduled to allow "acclimatization" of the astronaut and provide optional work-rest periods. This should particularly apply to the scheduling of lunar surface activities.

6. Substantial differences in astronaut response are observed. As a contingency measure it may be possible to select astronauts for the Apollo lunar surface mission who have shown lower metabolic outputs in EVA and/or simulations.

ACKNOWLEDGEMENT

This report benefited materially from discussions with Mr. H.S. Brownstein and Dr. F.B. Benjamin of NASA/MM. Special thanks are also due to Messrs. G.T. Orrok, P.R. Knaff and F.G. Allen of Bellcomm.

Donald B. Hoffman
D.B. Hoffman

A.N. Kontaratos

1011-DBH/ANK-bl

Attachment
Tables I and II

Copy to
(See next page)

Copy to
Messrs. L.O. Anderson - NASA/RBH
F.B. Benjamin - NASA/MM
J. Bollerud - NASA/MM
H.S. Brownstein - NASA/MM
T.A. George - NASA/MTX
H. Hall - NASA/MTX
S.H. Hubbard - NASA/MGO
D.W. Jenkins - NASA/SB
W.L. Jones - NASA/RB
T.A. Keegan - NASA/MA-2
D.R. Lord - NASA/MTX
E.J. McLaughlin -NASA/MM
K.F. Okano - NASA/MAR
L. Reiffel - NASA/MA-6
R.F. Trapp - NASA/RBA
J.H. Turnock - NASA/MA-4
S.P. Vinograd - NASA/MM
L.N. Werner - NASA/MTX

C.A. Berry - MSC/DA
L.F. Dietlein - MSC/DB
R.S. Johnston - MSC/EC
E. Michels - MSC/DB2

G.M. Anderson
T.A. Bottomley, Jr.
D.R. Hagner
P.L. Havenstein
W.C. Hittinger
B.T. Howard
D.B. James
P.R. Knaff
J.Z. Menard
I.D. Nehama
G.T. Orrok
T.L. Powers
I.M. Ross
P.F. Sennewald
T.H. Thompson
R.L. Wagner
All Members, Division 101
Central File
Dept. 1023
Library

TABLE I

EVA PHYSIOLOGICAL DATA

MISSION	AVERAGE HEART RATE (beats/min)	AVERAGE VENTILATION RATE* (respirations/min)	SENSATIONS	THEORIZED** METABOLIC COST (BTU/hr)	EVA DURATION (min)
Gemini 4	145-150 (150 peak)	25-28 (32 peak)		High	22
Gemini 9	150-155 (180 peak)	20-25 (40 peak)	-Fatigued -Gasping -Sweating	2200 Average 3600 peak	120
Gemini 10	115-120 (135 peak)	20-23 (26 peak)		High	38
Gemini 11	(180 peak)	(40 peak)	-Fatigued -Gasping -Sweating	High	26
Voshkod 2	135 (168 peak)	High	-Excited -Could hear own heart beat -Sweating	High	10
Resting human	60-70	12-16	--------	300-400 (measured)	-----

*Volume intake during hyperventilation increases above normal.

**Metabolic measurements were not made during EVA

TABLE II

METABOLIC BASE LINES

TREADMILL EXERCISE	SUIT TYPE	DIFFERENTIAL PRESSURE PSIG	HEAT PRODUCTION (BTU/hr)
0.8 MPH	Street Clothes	0.0	562
0.8 MPH	Gemini	0.0	780
0.8 MPH	Gemini	3.7	1171
1.5 MPH	Gemini	0.0	996
1.5 MPH	Gemini	3.7	1979