A HUMAN FACTORS ANALYSIS OF
EVA TIME REQUIREMENTS

10

Final Report
NASA/ASEE Summer Faculty Fellowship Program -- 1995
Johnson Space Center

Prepared By: Dennis W. Pate

Academic Rank: Lecturer

University & Department: Texas A&M University
                                      Engineering Technology Department
                                      College Station, TX 77843

NASA/JSC

Directorate: Safety, Reliability, and Quality Assurance

Division: Flight Systems Safety and Mission Assurance

Branch: Analysis and Risk Assessment

JSC Colleague: Dr. Richard P. Heydorn

Date Submitted: August 8, 1995

Contract Number: NGT-44-001-800

ABSTRACT

Human Factors Engineering (HFE), also known as Ergonomics, is a discipline whose goal is to engineer a safer, more efficient interface between humans and machines. HFE makes use of a wide range of tools and techniques to fulfill this goal. One of these tools is known as motion and time study, a technique used to develop time standards for given tasks. A human factors motion and time study was initiated with the goal of developing a database of EVA task times and a method of utilizing the database to predict how long an EVA should take. Initial development relied on the EVA activities performed during the STS-61 mission (Hubble repair). The first step of the analysis was to become familiar with EVAs and with the previous studies and documents produced on EVAs. After reviewing these documents, an initial set of task primitives and task time modifiers was developed. Videotaped footage of STS-61 EVAs were analyzed using these primitives and task time modifiers. Data for two entire EVA missions and portions of several others, each with two EVA astronauts, was collected for analysis. Feedback from the analysis of the data will be used to further refine the primitives and task time modifiers used. Analysis of variance techniques for categorical data will be used to determine which factors may, individually or by interactions, effect the primitive times and how much of an effect they have.

INTRODUCTION

International Space Station Alpha (ISSA) will require unique procedures in the construction and maintenance of the facility. Never before has mankind endeavored such an engineering and construction feat in such an alien environment. Many of these procedures will require extravehicular activity (EVA) time. There have been several major studies performed to determine the amount of EVA time required in the construction phase of ISSA and in the operational phase (required maintenance). Many of the studies indicate EVA time will be a major issue.

For ease of maintenance, ISSA is being designed with components, orbital replacement units (ORUs), that are replaceable by astronauts performing EVAs or using remote manipulator systems. Both require the expenditure of valuable astronaut time. Tools are currently being developed to better predict the likely failure rate of the ORUs. The number of ORU failures will determine the number of EVAs required. Early studies to determine the amount of EVA time required to replace the ORUs have varied greatly in their designs and in their findings. The variations between the studies is a direct result of the different methods people use to determine EVA time requirements. Currently, shuttle EVA timelines are developed by people with years of experience in the area of EVAs using their judgment to determine how the EVA should be conducted and how long it should take. These estimates are further refined by hours of practice by the astronauts who will perform the EVA. A large portion of shuttle EVA timelines attributed to overhead factors. The overhead is the non-productive time expended during an EVA mission. Planners regularly add between ten and thirty percent extra time to an EVA to account for individual differences and unexpected events. Even with this additional time, timelines are rarely met. This uncertainty in time makes predictions of future EVA time requirements difficult. To aid in more accurately predicting the amount of EVA time required for a given task, a human factors analysis of EVAs was initiated. This paper will present the considerations that went into the human factors analysis of the EVA time requirements, the state of the current analysis of the Hubble mission, and the planned future activities.

DISCUSSION

Motion and Time Studies

Motion and time studies involve observing a task, whether real time or recorded, and timing how long it takes to perform the basic movements of the task (known as "task primitives" in the EVA realm). The task primitives used in industry have undergone close to one hundred years of refinement. Frank and Lillian Gilbreth were among the first people to perform motion and time studies on industrial activities. They developed a set of task primitives, known as Therbligs, that could be used to describe all the task performed by a worker. The Therbligs are divided into productive and non-productive

activities. This distinction allows the analyst to identify and eliminate waste within an operation. The primitives are useful both in the analysis and in the planning stages of a task. In planning, databases containing the standard times allowed for the various task primitives from prior motion and time studies can be used to predict how long a task should take. These predicted times can be adjusted for worker specific traits as well as environmental factors. Factors such as training, physical abilities, and motivation may have large effects on the times.

The unique environment of EVA precludes using the Therbligs in the analysis of EVAs. The EMU the astronaut wears prevents viewing many of the visual queues an analyst of this system requires to determine what is going on. For this reason, the basic system was modified to accommodate the EVA environment.

EVA Timeline Resources

A review of the NASA document database was conducted to locate EVA related materials that may have contained information useful in the development of the modified motion and time study system. The EVA documents were reviewed to determine their exact content. None of the documents located were a complete source of EVA timelining information, however, some did contain a few task primitives with their associated times as well as some general guidelines to be considered when developing a timeline. The main source of EVA information is the experience and intuition of the people working in the EVA area. Unfortunately, much of this experience and knowledge has yet to be collected into a single common EVA reference resource.

The Fisher-Price study, *Space Station Freedom External Maintenance Task Team: Final Report,* was one of the most comprehensive studies of EVA activities conducted to date. A motion and time study of task primitives performed in prior EVA missions and WETF training sessions was conducted as part of the study to determine how long it would take to perform certain key task. The task primitives were used to predict how long EVA maintenance missions would take. This study did not address the issue of task time modifiers effecting the task times.

The MOD training library contains two volumes of an EVA training manual entitled *EVA Lessons Learned.* The manuals contain observations from all of the past EVA missions and also includes a listing of EVA task primitives; however, the task primitives are taken directly from the Fisher-Price study.

Post-flight analysis of each mission are also available. These report how much time the major task required, but do not report the data at the task primitive level. They do provided a means of identifying the EVAs that did not meet the planned mission time. These could then be reviewed to determine what factors may have effected the times.

A copy of a post-flight EVA analysis report of STS-51A was obtained from the EVA office. The report included comparisons between task times in the WETF and the inflight task times. The report also contained a listing of task primitives and their associated times. Some of the primitives included a general observation of possible task time modifiers.

Task Primitives

The Therbligs used in the traditional motion and time study were used as a starting point in developing the task primitives used in the EVA analysis. The following is adapted from Niebel:

A. *Effective*
   1. *Physical basic division*
      a. *Reach*
      b. *Move*
      c. *Grasp*
      d. *Release*
      e. *Pre-position*
   2. *Objective basic division*
      a. *Use*
      b. *Assemble*
      c. *Disassemble*
B. *Ineffective*
   1. *Mental of semimental basic division*
      a. *Search*
      b. *Select*
      c. *Position*
      d. *Inspect*
      e. *Plan*
   2. *Delay*
      a. *Unavoidable delay*
      b. *Avoidable delay*
      c. *Rest to overcome fatigue*
      d. *Hold*

Some of the Therbligs rely on being able to determine where the subjects gaze is. This is not possible when viewing an astronaut within an EMU. The gold visor obscures their face during the day and the poor lighting and reflections obscure their face during the night. This also hinders determining what activities may be going on during a delay. Times when the astronaut are eating, drinking, or resting cannot be distinguished from each other. The following is a list of the task primitives used in the initial study along with a brief description of the primitives:

- <u>Adjust</u> - the action of modifying a setting of a tool, PFR, or MFR

- <u>Assemble</u> - the action that occurs when two or more components are joined together.

- <u>Delay</u> - any time during which no work is occurring.

- <u>Disassemble</u> - the action that occurs when two or more components are taken apart.

- <u>Grasp</u> - the action of closing the fingers around an object.

- Hold - the action of supporting an object that is not being (dis)assembled or transported.
- Inspect - the action of visually checking an object to determine something about it.
- Operate - the action that occurs when work is being performed with a tool.
- Plan - the action of deciding what operation or task is to occur next.
- Position - the action of properly orienting and aligning an object.
- Reach - the action of moving a hand to or from an object.
- Rotate - the action of moving a PFR or MFR about its axis.
- Search - the action of locating an object.
- Select - the action of selecting one object from among a large number of objects.
- Tether - any action involving the use of a tether.
- Transfer - the action of transporting an object that is within the grasp on the astronaut.
- Translate - the action of moving from one position to another.
- Translate command - the action of communicating the desired RMS translation the IV RMS operator.
- Verify - the required action of checking with the IV operators to ensure the proper tool setting or procedure.
- Wait - a delay due to someone else.

The task are further divided into different classes (e.g. Translate: manual, Translate: RMS, Tether: select, Tether: open, etc.) Further refinement of the primitives will likely become necessary as the analysis of the Hubble mission continues.

Task Time Modifiers

To increase the power in predicting how long an EVA will take, one must have an understanding of the factors that may have an effect on the task times and what the effect will be. A list of factors effecting EVA times was developed from reviewing the lessons learned documents and other resources. Factors from the human factors field were added to these to develop the initial list used in the data collection and analysis of STS-61 (Hubble). In reviewing the EVA documents, the times given for the few task primitives listed were averages of observed times from past missions. The times did not include information on how to adjust the base task time for possible task time modifiers. Timeliners know from experience that task performed while free-floating will take longer than task performed while within a foot restraint

The astronaut performing the EVA is one of the largest sources of possible task time modifiers in the EVA system. The anthropometry (physical attributes) of the individual, their training, motivation, prior EVA experience, and mental ability will all have

an effect on their ability to perform an EVA task. A female who is in the 5th percentile strengthwise (i.e. given all the females in a population, 95 percent of the females will be stronger) will have different capabilities than a 95th male. There will be individual differences in stature, stamina, and strength. The intrinsic characteristics of the individual must be considered when predicting the time required to perform an EVA.

Related to this would be the posture the astronaut is in while performing the task. Some postures are biomechanically superior to others. Task times will be effected if the astronaut is in a twisted, extended, or otherwise contorted posture.

Another astronaut dependent factor would be the case of side dominance. Everyone has a dominant or preferred side (e.g. left or right). Task performed with the dominant side will be faster, more powerful, and more precise than those performed with the non-dominate side.

When analyzing a task time, one must consider the previous task(s) performed by the astronaut and the stamina of the astronaut. If the astronaut has just finished a labor intensive task or has been waiting on a reply from mission control, they may require more time to perform the next task. The longer they are into the mission, the more likely they are to slow down. The slow down may be offset, though, by the motivation factor. If the astronauts are behind on their schedule, they may push themselves at a faster pace than they normally work at.

The amount of training and the type of training an EVA astronaut receives will also effect the EVA time. Space station EVAs will not be practiced to the same degree shuttle EVAs are practiced due to time and monetary constraints. The effect the difference in training will have must be considered when predicting the time future EVAs will require. Ideally, a person should be trained until they reach the asymptote of their learning curve. This is the point where further training has no effect on the time required to perform the task. The training should continue till just prior to the mission. The longer the interval between their training and the actual performance of the task, the longer the inflight task time will take due to recall and relearning. The STS-61 EVA missions were the most highly trained for EVA missions to date. This must be considered when including the data from this mission with the data from other missions. This mission also included many astronauts with prior EVA experience. This would increase the confidence of the astronaut as well as increase the value of the training they received prior to the mission. One must also be aware of the possible negative results of training; that is, actual task will require more time than the same task performed during training due to learning the wrong methods. An example of this would be material positioning task learned in the WETF. In the WETF, the water provides a damping action to the positioning task making it easier to stop the load than in orbit, yet it requires more force to start the object into motion. Another effect of training in the WETF leading to negative training is the pain induced by floating upside down. When the astronaut is upside down, their weight is supported by their collar bones resting on the bearing ring in the collar of the EMU. This leads astronauts to practice in a predominately heads-up manner. When in space, they may experiment with a heads-down attitude leading to a change in the planned activities and times.

The external lighting environment during the EVA will also effect some of the task times. When in sunlight, visual task will be performed with greater ease. When out of the sunlight, lighting deficiencies become apparent and visual task will be hampered by the low light levels within the payload bay. During STS-61, the EVA astronauts required the IV crew to shine a flashlight through the orbiter window to provide more lighting for the task. Lighting induced psychological effects on the astronauts will also be possible. Some of the astronauts have commented that it is unsettling when you are on the RMS arm above the shuttle at night and everything except the shuttle is pitch black.

The thermal environment is also a function of the day and night conditions and will have an effect on the task times. During the night, the temperature will drop. As the temperature drops, the extremities, namely the fingers and hand, will cool at a faster rate than the bodies core. Conductive cooling that occurs while handling materials during the night can be severe enough to cause frostbite. Even a moderate cooling of the hands will cause a loss in the dexterity of the hands leading to an increase in the task times and an increased risk of accidents. Time will also be required to allow for the astronauts to put on a pair of protective thermal mittens. The thermal mittens may no longer be required when the actively heated EVA gloves are manifested on futures flights. The changing thermal environment can also cause equipment problems. PFRs may become difficult to ingress during the day when the boots and the PFR are thermally expanded. During the viewing of the Hubble mission, one of the astronauts had difficulty in ingressing a PFR attached to Hubble. The other astronaut had to interrupt their work to assist the ingress. In another incident, the astronaut could only ingress their right foot. Thermal vacuum chamber testing has helped to reduce the occurrence of thermal expansion and contraction problems, but they still need to be considered.

The restraint of the astronaut will also effect the time required to perform a task. A firmly restrained astronaut will be faster than one who is performing a task while free-floating. Task performed in these two different conditions must be differentiated.

The metabolic load the astronaut is under will also impact the task times. If an astronaut is under a heavy metabolic load, they will be producing large amounts of heat and CO_2 that must be removed from the EMU system. If they operate beyond the ability of the system, their body will respond by slowing them down to reduce the metabolic heat load and CO_2.

Some of the task times will be subject to task modifiers unique to the task. While translating, factors such as encumbrance and obstacles must be considered. Direction of travel may also be important when looking at such things as rotational movements, and positioning task.

Interruption in the EVA activities can have a negative impact on task times. Story Musgrave describes EVA as a type of ballet. This is a useful and appropriate analogy to many task. Once you start the EVA/ballet, you enter a routine where everything starts to flow and your thinking about the entire EVA/ballet as a whole, not just the next move. Whenever you interrupt the EVA/ballet, it will take some time to again get into the routine.

Data Collection

Videotapes of the entire STS-61 mission were obtained for analysis. These tapes included both onboard video (video recorded on tape recorders in the orbiter) and downlink video (video transmitted to mission control). Ideally the videotape to be analyzed included both the audio track and a time encoding. The audiotrack helped to determine the exact activity the astronaut was performing and determine what the pauses were for. Little useful information can be collected in the absence of the audio track. An essential tool used in conjunction with the audiotrack is the EVA timeline contained in the Flight Data File for the mission. The timeline allows one to know what is going on in the video and what operations are taking place. This also allows the analyst to know when the mission is deviating from the planned mission. The time encoding allows for the easy analysis of the time required to perform a task. It is possible to collect useful information in the absence of the encoding by using a stop watch to time the activities. This is cumbersome and does not allow for the slow motion analysis that is sometimes required to get a precise time.

The downlink video had a lower resolution than the onboard video, however, many of the onboard videos lacked either the audio tracks or time encoding. Initial data collection was performed using the downlink footage. This footage was taped in the order of the EVA missions and more attention had been paid to the focusing of the cameras on the activities that were being performed. Onboard videos were used to supplement the downlink videos when the astronauts were out of view in the downlink footage or the downlink was lost due to the lack of complete TDRS coverage. Even when making use of the two video sources, gaps in the coverage of a given EVA mission still exist.

The resolution and lighting of the videotapes is a problem in performing the motion and time study. At times the video image flares to white when the camera is over exposed with light and at times it fades to black when the light level drops on the camera is under exposed.

A studio quality tape player was used to play the tapes. The recorder allowed the speed of the tape to be controlled without a loss in the resolution of the image. This allowed speeding through portions of the video where there was no activity and slowing down for portions where there was a lot of activities occurring requiring close observation.

A spreadsheet to record the data was created using Microsoft Excel. The spreadsheet had space for the following information to be collected:

- Reference number within the data base
- Astronaut performing the task
- Planned time of the task
- Actual time of the task
- Timeline procedure from the Flight Data File
- Task primitive

- Task class of the primitive
- Task description containing supplemental information
- Starting time of the task
- Stopping time of the task
- Elapsed time of the task
- Hand used for the task (left, right, both)
- The task
  - Direction (CW, CCW, left, right, etc.)
  - Value (ft, revolutions, etc.)
  - Encumbrance
  - Obstacles
  - Rate (ft/sec, rev/sec, etc.)
- View
- Light (day, night, helmet lights, helmet and spot, etc.)
- Restraint (free, holding with left hand / right hand, PFR, MFR, etc.)
- Posture (neutral, twisted, hunched forward, etc.)
- Metabolic rate
- Errors committed
- Comments

This information will allow for the analysis of the times required for the task primitives and for analyzing the effects of the possible task modifiers. The database will be modified to reflect any lessons learned from the initial data collection performed on the Hubble EVAs.

Analysis

Analysis of the data collected on from STS-61 is currently in progress. Most of the analysis will be performed using the PC SAS statistical package. The following section presents an example of the analysis currently performed. The task primitive being analyzed is the "Rotate MFR" primitive. The data set is comprised of information collected from two different astronauts, EV1 and EV2. Table 1 presents the results of performing t-tests comparing the rotation rates of EV1 to EV2. None of the results are significantly different, but we can discern some qualitative differences between the two astronauts in reviewing the comments section of the data. In clockwise rotations, EV1 was large enough in stature to be physically capable of reaching around and grabbing the PWS and pulling himself around. EV2 had to rely on inertia to rotate around due to a small physical stature preventing the ability to reach around and grab the PWS. This is reflected in the t-value. The larger mass of EV1 also allowed him to have a greater rotational inertia when rotating without the aid of the stanchion.

Table 1. T-test comparing EV times.

EV1 to EV2	$t_0 =$	df =
CW to CW	0.296282	49
CCW to CCW	0.112795	38
CW to CCW	0.05151	37
CCW to CW	0.362592	50

Future Plans

Analysis of the currently collected data will continue. This will provide an insight into how the different task primitives should be handled and what types of adjustments will have to be made. Any necessary refinements to the system will also be made at this time. After the refinements are made, the remaining EVAs from STS-61 will be analyzed to build up the database. Data will also be collected from the WETF training sessions with the hope of determining the correlation factors between WETF times and flight times.

ACRONYMS

EMU	extravehicular mobility unit
EVA	extravehicular activity
ISSA	International Space Station Alpha
MFR	manipulator foot restraint
PFR	portable foot restraint
PWS	portable work stanchion
RMS	remote manipulator system
TDRS	tracking and data relay satellite
WETF	weightless environment trainer

REFERENCES

Fisher, William F., Price, Charles R., *Space Station Freedom External Maintenance Task Team, Final Report*, vol. I, parts 1-2, July 1990, NASA

Niebel, Benjamin W., *Motion and Time Study*, 8th ed., Homewood, Il.:Irwin, 1988.

NASA, *EVA Lessons Learned*, vol. I, October 1994.

NASA, *EVA Lessons Learned*, vol. II, October 1994.

NASA, *STS-61 Flight Data File*

NASA, *STS-61 Videotape Scenelist*, JSC-25945-61