(2)

AD-A199 268

AFWAL-TR-87-3103

Proceedings of the Workshop on the Assessment of Crew Workload Measurement Methods, Techniques, and Procedures:

Part-Task Simulation Data Summary

George P. Boucek, Jr.
Diane L. Sandry-Garza
Aileen L. Logan
Boeing Commercial Airplanes

Michael A. Biferno
William H. Corwin
Sam Metalis
Douglas Aircraft Company

February 1988

Proceedings for Period 15-16 September 1987

Flight Dynamics Laboratory
Air Force Wright Aeronautical Laboratories
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio 45433-6553

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

Michael H. Pharaoh

MICHAEL H. PHARAOH, Sqn Ldr, RAF
Electrical Engineer
Crew Systems Development Branch

Ronald I. Morishige

RONALD I. MORISHIGE, Lt Col, USAF
Chief, Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER

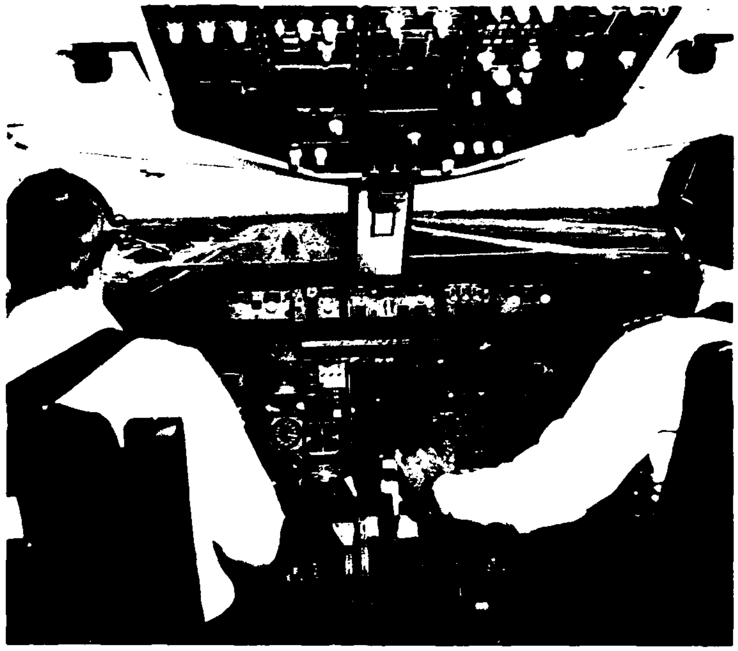
Eugene A. Smith

EUGENE A. SMITH, Lt Col, USAF
Chief, Flight Control Division
Flight Dynamics Laboratory

If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/FIGR, Wright-Patterson AFB, OH 45433-6553 to help us maintain a current mailing list.

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

Control of the Crew Caused Accident



RESULTS OF A 12-OPERATOR SURVEY

by
L.G. Lautman
Engineering Safety
and
P.L. Gallimore
Flight Operations Support

The air safety record has improved substantially in the decades since introduction of the jet transport in 1959 and throughout the period crew caused accidents dominated all other accident causes by a wide margin (Figure 1). It has consistently accounted for over 70% of the major (fatal or hull loss) accidents in spite of increasing attention to cockpit resource management programs and other human factors areas.

In 1986 we concluded a study of accident reports to better understand accident cause factors. A total of 126 major accidents which occurred worldwide during the period 1977 through 1984 were examined. From this group of accidents, 93 were identified where enough information was available to allow the determination of significant cause factors. The crew cause factor classifications and their percentage of presence in these 93 accidents are

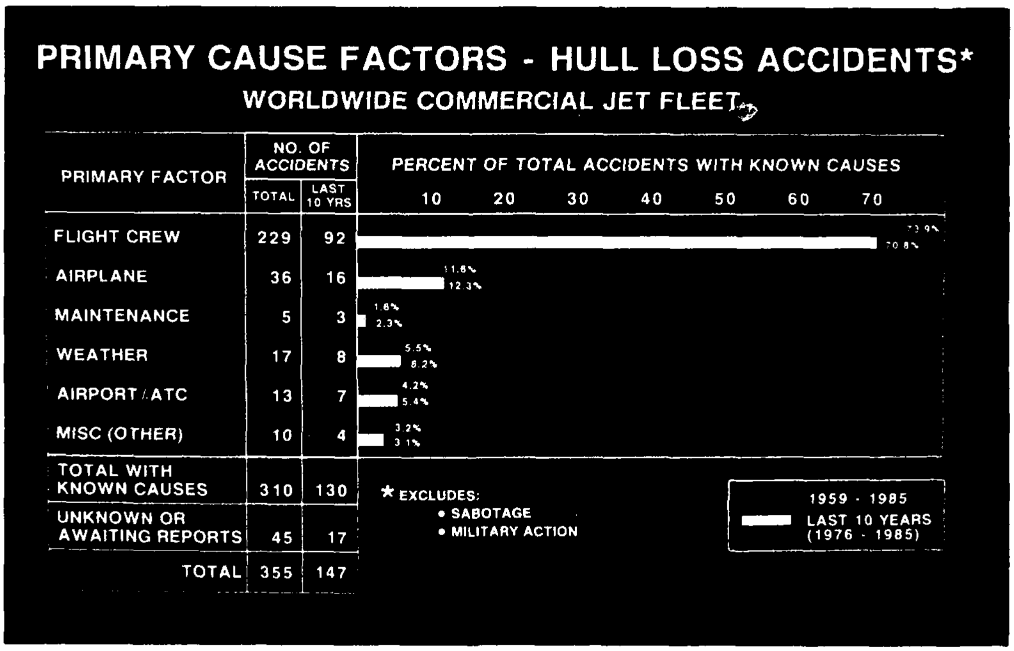


Figure 1. The distribution of causal factors in hull loss accidents between 1959-1985 as compared to 1976-1985 is depicted here.

shown in Table 1. Effective control of these flight crew accident factors will depend largely on the airline operation and training community.

33%	**Pilot deviated from basic operational procedures.**
26%	**Inadequate crosscheck by 2nd crew member.**
9%	**Crews not conditioned for proper response during abnormal conditions.**
6%	**Pilot did not recognize the need for go-around.**
4%	**Pilot incapacitation.**
4%	**Inadequate piloting skills.**
3%	**Pilot used improper procedure during go-around.**
3%	**Crew errors during training flights.**
3%	**Pilot not trained to respond promptly to GPWS command.**
3%	**Pilot unable to execute safe landing or go-around when runway sighting is lost below MDA or DH.**
3%	**Operational procedures did not require use of available approach aids.**
3%	**Captain inexperienced in aircraft type.**

Table I. Significant crew cause factors and percentage of presence in 93 major accidents.

Examination of worldwide accident history shows that some operators have more accidents than others. Using the Boeing fleet over a ten-year period as an example, 16% of the operators have crew caused accident rates higher than the fleet average and these operators account for over 80% of the total accidents. Conversely, 80% of the operators had no crew caused accidents over the same period. The distribution of accidents for the fleet is shown in Figure 2.

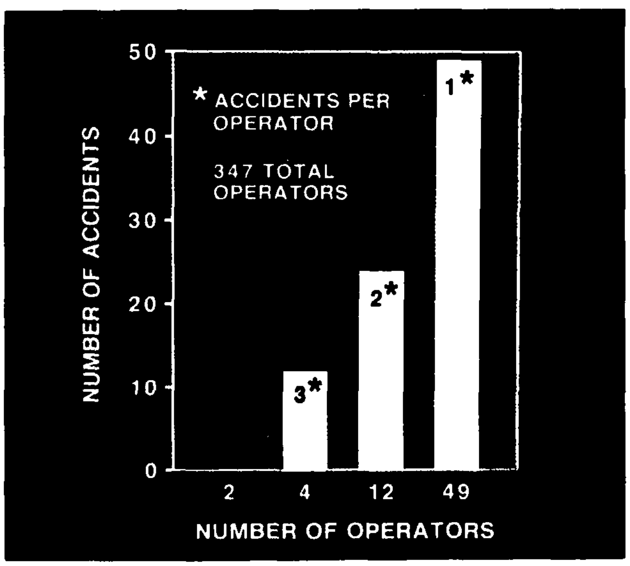


Figure 2. The distribution of crew caused accidents involving operators of Boeing airplanes between 1975-1984.

Boeing recently contacted a small group of operators, most of which had better than average crew caused accident history. This was done with a view to obtaining information on techniques which contribute to safe operations and which could be brought to the attention of all operators through our Flight Operations Support Program (FOSP) where we provide pilot-to-pilot contact with the operators. Over a two-year period 12 operators were contacted. Meetings with management pilots in the flight operations and training departments focused on what was considered by the operators to be key elements of safe operation. It is the results of these informal meetings that are summarized here. To avoid repetitious qualifying phrases denoting the degree of consensus on any point the reader may assume a reasonable consensus unless the individuality of the comment is emphasized. The findings are grouped for convenience of presentation only. The format does not imply a structured approach to the discussions held with the operators.

Management Emphasis on Safety

In the broad context of management these operators characterize safety as beginning at the top of the organization with a strong emphasis on safety and this permeates the entire operation. Flight operations and training managers recognize their responsibility to flight safety and are dedicated to creating and enforcing safety-oriented policies. The presence or absence of a safety organization did not alter the total involvement of these managers. However, a majority of the operators did maintain an identifiable flight safety focal point. There is an acute awareness of the factors that result in accidents, and management reviews accidents and incidents in their own airline and in other airlines and alters their policies and procedures to best guard against recurrence. There is a method for getting information to the flight crews expeditiously and a policy that encourages confidential feedback from pilots to management. This management attitude, while somewhat difficult to describe, is a dynamic force that sets the stage for standardization and discipline in the cockpit brought about and reinforced by a training program oriented to safety issues.

Standardization and Discipline

Management recognizes the need for aircrews performing in a standardized way and the importance of cockpit discipline in providing the environment for proper crew coordination. This results in a number of specific policy implementations:

- A standardization pilot and a standardization flight engineer (if applicable) are appointed, usually one for each type airplane in the fleet. All procedure and checklist issues are coordinated by the standardization personnel recognizing differences in airplane and cockpit configuration within the type.

- A strong check airman program acts as a continuous quality control check on the training department. Standards for check airman candidates exist in writing and the highest level of flight operations management participates in the evaluation and selection process. Methods exist for assuring the uniformity of check pilot techniques and instruction, usually accomplished during periodic (monthly) meetings of all check pilots. There is a special system of recurrent checks for check pilots that is indepenuent of the line pilot recurrent training program. An effort is made to assure the uniformity of checking techniques by correlating reported non-standard behavior in students to individual check pilots where possible.

- There is a firm requirement for in-depth takeoff and approach briefings for each flight segment. This provides the entire crew with knowledge of precisely how the event is to be performed. The takeoff briefing is a review of departure plans, rejected takeoff (RTO) technique, and contingency plans in the event of an emergency calling for return to the departure airport. One operator requires an RTO *touch drill* where each control used during RTO is sequentially touched by the pilot who will be making the takeoff.

- The approach briefing is usually done at the top of descent before workload increases. It covers the navigation, communication and procedural details of the approach for the specific runway involved, including missed approach details.

- Cockpit procedural language is tightly controlled to maintain consistency and to avoid confusion from non-standard callouts which can result from crew members using differing phraseology. Callouts and responses are done verbatim. The recurrent training program and check pilot system rigidly enforce this requirement.

- The large operators, operating several airplane types (often of more than one manufacturer) devote a good deal of effort to standardize checklists and operations manuals to meet their operational philosophy and format. A few feel that cockpit configuration standardization is essential and that the money is well spent to keep cockpits as nearly alike as possible.

- All operators surveyed prefer accomplishing their own training so that positive control of standardization and discipline can be maintained. About half provide training for other operators. They voiced concern that in order to cut costs, buyers of training will request a training program less extensive than the seller uses to train his own crews and noted the difficulties this imposed on training contract negotiations. Of course where the seller leases unmanned facilities to a buyer who provides the training personnel the seller loses any say in the quality of training.

- It was also felt that airlines that buy training from the lowest bidder may experience a lack of standardization. This results from the fact that: 1) New-hire rated pilots may not receive complete coverage of company philosophy and procedures, 2) Initial and recurrent training may not be bought from the same source and 3) The source of recurrent training may change from time to time. Too often the airlines we visited who perform contract training see a crew arrive for training where each pilot's prior training has been with a different contractor. Sometimes the pilots even have different operating manuals which were obtained during their respective training programs. These types of problems make it difficult to attain a satisfactory level of standardization, communication and smooth performance as an integrated crew.

- The on-site availability of full-flight simulation is a tremendous boost to conducting a high quality flight crew training program. With the exception of one or two airplane types where fleet size would clearly not justify the expense of dedicated simulators the operators visited often stretched themselves financially to have a full flight simulator for each type in the fleet. In the few cases where the simulators were not owned the operators leased simulators and provided the instructors from their own ranks. For the 12 operators the simulator types owned as a percentage of fleet airplane types was 90%. As a matter of comparison the operators who have worse than average accident rates have only a 60% coverage of the fleet with company-owned simulators.

Recurrent Training

The criticality of recurrent training to continued safe operation is universally recognized. Many of the issues discussed in other sections of this article are implemented through a training program that recognizes and provides emphasis on accident related operational topics such as windshear, ground proximity warning system (GPWS), rejected takeoff and human factors.

All operators stressed the importance of a well managed and thorough recurrent training program. Most of the operators surveyed train captains and first officers to the same standards and provide the same quality and quantity of training to both. Half of the operators also type-rate all pilots to the same standards. A few provide simulator training four times per year. One operator who had established a standard of four recurrent training sessions per-year per-crew attempted to cut training costs by reducing the training sessions to two per-year for crew members who were located at a remote domicile. After a trial program this operator reverted to the basic four sessions per year based on a noticable degradation of piloting skills in the two-per-year crews. This skill loss was particularly noticeable for the lower 20 percent of the pilots.

Firm rules exist and are enforced if poor performance is noted in training. No flying is permitted until satisfactory performance is demonstrated. If problems persist, high level management faces up to the tough decisions of alternate assignments, demotion or dismissal.

Several operators regularly cycle training captains through a line-flying period to keep them in touch with actual operations.

Flight Path Control

Since the approach and landing phase accidents comprise such a large segment of the total accident picture (Figure 3) it is not suprising that we found much emphasis being placed on the stabilized approach and proper energy management. It is felt that reduced flap settings and late gear extension brought about by fuel conservation measures contribute to destabilized approaches. The more modern, aerodynamically clean, airplanes can pose problems for a crew that does not plan the approach sufficiently in advance. Speed and altitude can be difficult to bleed off if the ideal approach path is overshot and/or airspeed is too high. Higher thrust settings for engine anti-ice, if required, make matters that much worse. ATC often can place the airplane close-in and high and, if the

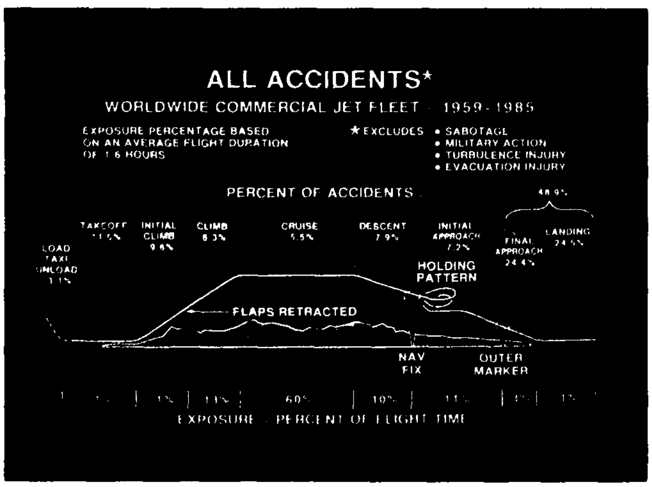


Figure 3. The flight segment distribution of all commercial accidents between 1959-1984.

crew is not alert, the speed which must be dissipated may preclude attaining a stabilized landing configuration at a reasonable altitude. If the approach is not stabilized it is more difficult to detect the effects of windshear and in fact any changing wind conditions. When the approach becomes hurried normal monitoring and crew coordination are subject to breakdown and the stage is set for a landing accident. Management and training emphasis was found in the following areas:

- There are firm rules for flap and gear extension versus altitude. There is often a cutoff altitude specified where, if the airplane is not on glide path in landing configuration with speed stabilized, a go-around is mandatory. These altitude gates are usually different for instrument and visual conditions.

  As an example, one operator who places stringent management controls on approach techniques begins with the simulator phase of transition training. Parameters for control of the approach must be committed to memory. For given landing configurations the approximate attitude, thrust setting and vertical speed targets are committed to memory and applied so that the following rules for the approach can be met:

  1. The airplane **should** be stabilized in landing configuration by 1000 feet above touchdown. If there is significant crosswind, low clouds or poor visibility then the airplane **should** be stabilized by at least the outer marker.

  2. It **must** be stabilized by 500 feet and if not, an immediate missed approach must be initiated.

- There is a requirement for monitoring instruments including approach displays during visual approaches. One operator has a policy that whenever landing aids are available every approach is an instrument approach. Operational procedures and training reinforce the philosophy that the ability to see the ground is just an additional landing aid.

- The infrequent occurrence of the visual missed approach seemed statistically unreasonable to some operators and prompted them to emphasize the go-around decision in training, remove the requirement to report go arounds to management, and develop procedures which encourage the crew to make a go-around rather than attempt a landing out of a poor approach.

- One operator felt that early training (primarily military) over-emphasized the skills for a complete power-off approach and diminished attention to proper approach techniques.

First Officer Flying Rules

Some operators believe that captains do not always do the monitor functions well when the first officer is flying. This problem receives special training emphasis, to demonstrate that the captain in this circumstance really must perform all the first officer duties in addition to his pilot-in-command functions. (To better understand the individual crew member's involvement in this problem, Boeing studied crew caused accident history where it could be determined which pilot was handling the airplane. It was found that in a majority of the accidents the non flying pilot (NFP) had the opportunity to effect corrective action but failed to do so. However, the captain did not appear to be an ineffective NFP when compared to the first officer.)

There are usually specific rules governing when the captain must make the approach and landing. These vary widely from operator to operator but many had rules more specific than *Captain's choice* or *alternate legs*. These rules which specifically call for the captain to handle the airplane fall into four general categories:

- Airports that have geographic hazards or congestion problems.
- Weather minimums – most frequently below 1200 RVR or for Category II and III landings.
- When there is a primary airplane system malfunction.
- Low first officer time in type.

One operator determined that ground handling accidents and incidents were more frequent when the first officer was taxiing. A rule was adopted that requires the captain to taxi.

Line Oriented Flight Training (Loft)

LOFT was fully implemented in the recurrent training program for nine of the operators and partially implemented at two. Those operators who use LOFT were of the opinion that this training element is a very important safety enhancement. It provides a method of exposing a crew to a complete flight operation (such as preflight operations, the flight itself and the postflight activity) in such a way that company procedures, flight procedures, flying techniques and cockpit management (human factors) are observed without providing any more assistance to the crew than it would have on a real flight. Crew operating and teamwork shortcomings are reviewed in a debriefing by a training pilot. Some airlines have introduced video recording playback into the debriefing and found this beneficial in allowing self-critique by the pilots.

Thoughtful preparation of LOFT scenarios is essential in order to provide a maximum of crew decisions, actions and opportunity for error in a realistic flight that has an abundance of high crew workload and stress. Some operators see a need for more realistic scenarios with less emphasis on multiple failures in non-critical phases of flight and more emphasis on realistic situations in the approach and landing phases. Creating enough scenarios to adequately cover the training objectives and to prevent crew familiarity through repetition was a frequently mentioned problem.

Reference Data

Some operators are concerned that automated dispatch, computerized airport analysis and flight planning although considered essential in today's operation may reduce the pilots' familiarity with the performance capability of the airplane. One operator is increasing emphasis on this aspect in the training program.

More on Management

The key safety elements discussed so far were recognized by management as significant safety concerns upon which they placed almost universal emphasis in each of their respective flight training programs. The items below are more random in nature and do not lend themselves to catagorization but they too fit the mold of key elements.

- Flight data recorder monitoring is being practiced by 3 of the 12 operators primarily as a tool to provide direction to the training department. The digital recorder tapes for each flight are compared by computer against predetermined standards for specific flight phases. Substantial deviation from standards such as early rotation, high descent rate, unstabilized approach and high touchdown speeds are automatically identified for further investigation. The operators who have implemented this system are very enthusiastic about its contribution to safety and have found ways to structure the program so that flight crew concerns are addressed and their support is obtained. Taking a serious flight-related event to the specific flight crew for review is done through the *Association* representative in the few instances it is required, but this aspect is considered of far less significance in comparison to the benefits derived in understanding where operational procedures and or the training program might need modification or emphasis.

- All operators have firm policies requiring immediate pull-up in response to a ground proximity warning in Instrument Meteorological Conditions (IMC) but only two investigate each case in order to determine the cause and verify that a proper response was made. Most operators express concern that unreliability of the early GPWS is still influencing some pilots to delay *pull-up* instead of initiating an immediate response. Several operators have already implemented GPWS response training in their simulator programs.

- Pilots are being made more aware of the significance of V_1 and the practical aspects related to aborting or continuing a take off. The criticality of actions to stop or to go when airplane speed is in the vicinity of V_1 is becoming better understood by the flight crews in these airlines.

- Problem airports receive careful analysis and management attention; special training, experience and currency requirements are laid down. The method of handling this problem varies from operator to operator. As an example one operator classifies all airports of interest into three categories and specifies certain landing requirements for each category. These are:

  1. Standard – all captains are qualified.

  2. Operational problems – 24 months with the airline as captain or prior operation into the airport as pilot or observer.

  3. Non-standard – as pilot or observer within last 12 months. In addition a number of the non-standard airports have more stringent requirements. One, for example includes:

     o First checkout with a training pilot

     o At least 5 takeoffs and landings before revenue flight

     o Minimum of 2 approaches, landings and takeoffs within the last 2 months

     o Landing by captain only

     o Night checkout prior to night operations

Where do we go from here?

The results of this limited study indicate that the potential for improvement of the crew caused accident rate may be great if some key policies, procedures and practices are adopted and followed. Figure 4 shows that this improvement might approach a factor of ten for the worldwide fleet if the rate for the 12 operators is statistically valid. A review of the nearly 350 Boeing operators shows that at least 54 have accident rates worse than average and therefore might benefit from a close look at their own standards, discipline, procedures and flight crew training programs (Figure 5).

Boeing will continue to investigate and expand its knowledge of crew caused accidents and communicate any findings to the operators.

To summarize, we are unable to prioritize the findings of this study since every aspect is important. However, the low crew caused accident carriers seem to have found the key to integrating the elements into a successful operation.

Our sincere thanks go to the 38 management pilots of the 12 airlines that gave so generously of their time and talents to make this first step possible. Comments from readers of this article, particularly more *Key Elements* for safe operation, would be most welcome. Please write to:

Boeing Commercial Airplane Co.
Attn: Safety Manager M/S 98-33
P.O. Box 3707
Seattle, WA 98124

Flight operations and training managers who are willing to provide details of their airline's operation in order to broaden the scope of this study may request a copy of a questionnaire developed for this purpose.

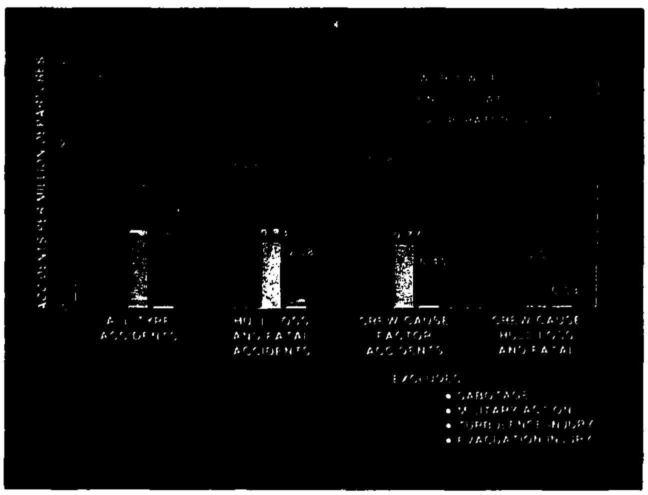


Figure 4. The jet transport accident rates for three classes of accidents occuring between 1975-1984 are compared in this illustration.

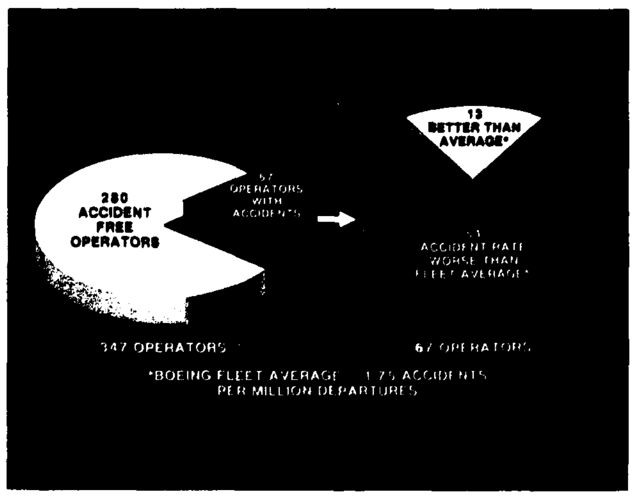


Figure 5. Crew caused accidents within the Boeing Fleet between 1975-1984.

AIRLINER Magazine

Issue	Page	Title
Oct 1983	1	Winter Operations – Keep It Clean
	8	Preparation for Winter Operations
	10	Pt2 Engine Inlet Probe Icing
Jan 1984	FCNL*	Go-Around Decision
	FCNL*	Stabilized Approach
	13	Approach and Landing – Back to Basics
Apr 1984	26	Go/No Go Takeoff Decision
Jul 1984	FCNL*	Fly the Numbers
Oct 1984	FCNL*	Winter Operations
Jan 1985	1	[illegible]
	FCNL*	[illegible]
Apr 1985	FCNL*	[illegible]
	20	[illegible]
Oct 1985	FCNL*	[illegible]
Apr 1986	[illegible]	[illegible]
	FCNL*	[illegible]
Oct 1986	[illegible]	[illegible]
	[illegible]	[illegible]
	FCNL*	[illegible]
	16	[illegible]
Jan 1987	FCNL*	[illegible]

*FCNL– [illegible]

[illegible]

Issue	Title
[illegible]	[illegible]
[illegible]	[illegible]

[illegible]

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b. RESTRICTIVE MARKINGS: NONE

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for Public Release: Distribution Unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S): AFWAL-TR-87-3103

6a. NAME OF PERFORMING ORGANIZATION: DOUGLAS AIRCRAFT COMPANY

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION: Air Force Wright Aeronautical Laboratories Flight Dynamics Laboratory/AFWAL/FIGR

6c. ADDRESS (City, State, and ZIP Code): Long Beach, CA, 90846

7b. ADDRESS (City, State, and ZIP Code): Wright Patterson AFB, OH, 45433-6553

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33615-86-C-3600

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO	WORK UNIT ACCESSION NO.
62201F	2403	04	50

11. TITLE (Include Security Classification): Proceedings of Workshop on the Assessment of Crew Workload Measurement Methods Techniques, and Procedures: Part-Task Simulation Data Summary

12. PERSONAL AUTHOR(S): G P Boucek, D L Sandry-Garza, A L Logan, M A Biferno, W H Corwin, S Metalis

13a. TYPE OF REPORT: Proceedings

13b. TIME COVERED: FROM 15 Sep 87 TO 16 Sep 87

14. DATE OF REPORT (Year, Month, Day): 1988 February

15. PAGE COUNT: 200

16. SUPPLEMENTARY NOTATION: Supported inpart by FAA

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	09	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Subjective measures,
Performance measures,
Physiological measures

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Proceeding of a two day workshop to review the results of a part-task simulation program to determine the validity, reliability and applicability of candidate workload measurement techniques intended for use during aircraft certification.

Keywords.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL: M H PHARAOH

22b. TELEPHONE (Include Area Code): (513) 255-8259

22c. OFFICE SYMBOL: AFWAL/FIGR

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

EXTRACT FROM DOUGLAS AIRCRAFT COMPANY LETTER

During the second Workload Workshop, held in Seattle during September, various data collected during our PART-Task simulation was presented. Data was presented for the Subjective Workload Assessment Technique (SWAT) and the NASA Task Load Index (TLX) which contained some errors. The following proceedings contains the correct data, and data analyses for both validity and reliability. None of the discriminability analyses outcomes changed for the correct data. The ability to discriminate LOW and HIGH workload remained the same, as well as the discrimination among individual "windows" of measurement and discrimination among phases of flight within LOW and HIGH workload, respectively. The reliability test/retest data was affected significantly by the analyses done with the correct data. SWAT, which did not appear to be very reliable from one session to the next, turned out to be nearly as reliable as the NASA-TLX data. TLX reliability coefficients slipped very slightly with the analyses redone with the correct data. The two measures, SWAT and TLX, appear to be more similar than originally presented at the Seattle workshop.

EDITED BY

George P. Boucek	Boeing Commercial Airplane Company Seattle, Washington
Diane L. Sandry-Garza	Boeing Commercial Airplane Company Seattle, Washington
Aileen L. Logan	Boeing Commercial Airplane Company Seattle, Washington
Michael A. Biferno	Douglas Aircraft Company Long Beach, California
William H. Corwin	Douglas Aircraft Company Long Beach, California
Sam Metalis	Douglas Aircraft Company Long Beach, California

ACKNOWLEDGEMENTS

The Editors would like to express their appreciation to Jon Jonsson, Douglas Aircraft Company, for providing crucial help and insight in the process of reducing and analyzing the data from the simulation experiment. Without his timely assistance and guidance the data would not have been completely analyzed before the second workshop.

Appreciation is also expressed to Mariel Sipman and David Nixon for their efforts during the data reduction and analyses of the PART-Task simulation data.

The Editors would also like to express their appreciation to Nancy Whitman for her efforts in coordinating hotel and catering arrangements and her on-site support during the workshop; Janet Camarata and Marji Yates for their efforts in preparation of the workshop documentation; and Gary Boley and Dan McGehee for their assistance during the workshop program.

TABLE OF CONTENTS

INTRODUCTION

Currently, The Boeing Company and Douglas Aircraft Company are jointly working a USAF/FAA sponsored workload contract. The objective of this contract is to provide guidelines for a flexible basis for selecting workload measures in future years as flight deck requirements change. This will enable the FAA to evaluate workload measurement plans for crew size substantiation and workload acceptability during aircraft certification efforts. Guidelines will be provided for selecting workload measures that are valid, reliable, and applicable for airplane certification.

The manufacturers of commercial transport aircraft are aware of the special responsibilities and caution needed to assure a safe aircraft design. The technical approach for this contract has emphasized established scientific methodology and practical application of methods in the selection of workload measures for aircraft certification. A step-by-step procedure has been used for identifying candidate workload measures and then confirming the validity, reliability, and applicability of the candidates by means of rigorous aircraft simulation testing. The procedures used have enabled quantitative descriptions to be made of the statistical validity and reliability of the workload measures employed in testing to date. —> 1473

Results from the part-task simulation testing phase of the contract were presented at a two-day workshop held in Seattle, Washington, on September 15 and 16 at the Crowne Plaza Hotel. Eighty attendees were drawn from a wide cross section of operational personnel and potential workload measurement users. University scientists from the first workshop held in Long Beach, California, on February 24 and 25, 1987 were invited to attend to help assess the scientific quality of the results and the appropriateness of the conclusions drawn from the data and test designs. The remainder of the attendees were from aerospace industry, government regulatory agencies, military workload experts, and NASA.

Attendees were asked to provide comments/discussion regarding their views of the part-task testing results. They were also asked to comment on the validity of the data and what the data suggested regarding the applicability of the candidate workload measures to aircraft certification. Audience comments were reviewed and incorporated prior to the full-mission testing phase of the contract. Included in these proceedings are copies of all the workshop presentations, results of analysis of the data collected in part-task testing and the results of the time-line analysis. In addition, a summary of the discussions held over the two days is included.

USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS:
PART-TASK SIMULATION DATA SUMMARY WORKSHOP

ATTENDEE LIST
WORKSHOP #2
September 15 and 16, 1987

Attendee Name	Phone
Donald Armstrong Federal Aviation Administration 4344 Donald Douglas Drive Long Beach, CA 90808	(213)514-6330
Dr. Randall B. Aust McDonnell Douglas Helicopter Co. Building 531, C240 5000 East Mc Dowell Road Mesa, AZ 85205	(602)891-6141
Dr. Frank Austin 800 Independence Avenue SW Washington D.C. 20591	(202)267-9451
Robert P. Bateman Boeing Military Aircraft Co. P.O. Box 7730 MS K78-08 Wichita, KA 67277-7730	(316)526-8765
Vern Battiste NASA-Ames Research Center Attn: MS-239-3 Moffet Field, CA 94035	(415)694-6249
Herb Berry Douglas Aircraft Company M.C. 75-11 3855 Lakewood Blvd. Long Beach, CA 90846	(213)593-1763
Dr. Michael A. Biferno McDonnell Douglas Corporation MC 209-01 3855 Lakewood Blvd. Long Beach, CA 90846-0001	(213)513-2031
Dr. Alvah C. Bittner Analytics 2500 Maryland Rd. Willow Grove, PA 19090	(215)657-4100

Michael R. Bortolussi (415)694-6187
NASA-Ames Research Center
Attn: MS-239-3
Moffet Field, CA 94035

George Boucek (206)237-7280
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Sqn. Ldr. Harry Britten-Austin (513)255-8259
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Capt. Robert G. Buley (612)726-3830
Check Airman-Flight Training
M/S G-7200
Northwest Airlines Inc.
7500 Airline Drive
Minneapolis, MN 55450

Kim Cardosi (617)494-2696
DOT/TSC
DTS-45
Kendall Square
Cambridge, MA 02142

Robert E. Chaney (206)656-5498
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 6L-38
Seattle, WA 98124-2207

Rob Chatfield (206)431-1557
Federal Aviation Administration
Flight Standards Division, ANM 277S
17900 Pacific Highway S.
C-68966
Seattle, WA 98168

Dr. Bill Connor (305)596-4549
Delta Air Lines, Inc.
1722 Ponce De Leon Blvd.
Coral Gables, Florida 33134

Dr. William Corwin (213)513-2002
McDonnell Douglas Corporation
MC 209-01
3855 Lakewood Blvd.
Long Beach, CA 90846-0001

Michael Dresel (206)526-7655
Boeing Military Aircraft Co.
P.O. Box 7730
MS K78-08
Wichita, KA 67277-7730

Terry Emerson (513)255-6344
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Delmar Fadden (206)342-3024
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 01-81
Seattle, WA 98124-2207

Charles W. Geer (206)251-4579
Boeing Aerospace Co.
P. O. Box 3999
MS 8K-03
Seattle, WA 98124-2499

Berk Greene (206)431-1994
FAA ANM-160S
17900 Pacific Highway South
C-68966
Seattle, WA 98168

Dr. Randell Harris (804)865-4685
NASA-Langley Research Center
MS 152E
Hampton, VA 23665

Wolf Hebenstreit (206)251-4579
Boeing Aerospace Co.
P.O. Box 3999
MS 2K-58
Seattle, WA 98124-2499

Dr. Peter V. Hwoschinsky (202)267-8531
FAA APM-430
800 Independence Avenue SW
Washington D.C. 20591

Dr. Richard S. Jensen (614)292-5462
Ohio State University
Dept. of Aviation
Box 3022
Columbus, OH 43210

Jon Jonsson (213)513-2011
Douglas Aircraft Company
MC 209-01
3855 Lakewood Blvd.
Long Beach, CA 90846-0001

H. H. Knickerbocker (213)593-2206
McDonnell Douglas Corporation
MC 41-58
3855 Lakewood Blvd.
Long Beach, CA 90846

Aileen Logan (206)237-7282
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Gary Lopez (617)273-7028
Federal Aviation Administration
New England Region, ANE-265
12 New England Executive Park
Burlington, MA 01803

Joseph MacDonald (206)655-2425
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 26-09
Seattle, WA 98124-2207

Teresa L. Mann (404)425-7668
Lockheed Georgia Co.
Marietta, Georgia 30063

Lt. Kim Mazur (513)255-8258
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Dean Melton (206)431-1989
FAA ANMN-160S
17900 Pacific Highway South
C-68966
Seattle, WA 98168

Dr. Henry W. Mertens Human Performance Research Unit FAA/CAMI Box 25082 AAC-118 Oklahoma City, OK 73125	(405)686-4846
Dr. Sam Metalis McDonnell Douglas Corporation MC 209-01 3855 Lakewood Blvd. Long Beach, CA 90846-0001	(213)513-2025
Thomas R. Metzler U.S. Army Research Institute AVSCOM PERI-IRA 4300 Goodfellow Boulevard St. Louis, MO 63120-1798	(314)263-2701
Daniel Mottard DGAC-SFACT 364 Rue DuLouvre 75001 Paris, France	
Dr. Susan Norman Chief Aeronautical Human Factors Research Office NASA-Ames Research Center Moffett Field, CA 94035	(415)694-5717
Harry W. Orlady Battelle ASRS Office 625 Ellis Street, Suite 305 Mountain View, CA 94043	(415)969-3969
Dr. Charles Overbey Operational Test & Evaluation Division FAA AST-200 800 Independence Ave., SW Washington D.C. 20591	(202)267-3248
Don L. Parks Boeing Military Airplane Co. P.O. Box 3707 MS 33-22 Seattle, WA 98124-2207	(206)655-7609
Dr. Evan Pickrel FAA AAM-500 800 Independence Avenue SW Washington, DC 20591	(202)267-3435

James Plakis (516)791-7144
FAA New England Region
New York-Aircraft Certification Office, ANE-170
181 S. Franklin Ave.
Valley Stream, N.Y. 11581

Gary B. Reid (513)255-8749
USAF/AMRL
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. John M. Reising (513)255-8274
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. Alan Roscoe 011 44
Britannia Airways Ltd. 582 424155
Luton Airport
Bedfordshire LU2 9ND United Kingdom

Bill Russell (202)626-4023
Air Transport Association
1709 New York Avenue NW
Washington, DC 20006

Diane L. Sandry-Garza (206)237-7279
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Dr. Richard Schiffler (513)255-4109
ASD/ENEC
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. Samuel B. Schiflett (512)536-3464
USAF SAM/VNB
Crew Technology Division
Brooks AFB, TX 78235

Robert J. Shivley (415)694-6249
NASA-Ames Research Center
MS 239-3
Moffet Field, CA 94035

Troy D. Sims (816)374-3946
FAA - Aircraft Evaluation Group
601 East 12th Street
Kansas City, MO 64106

Dr. Don Smith 7310 Valburn Drive Austin, TX 78731	(512)346-3499
Jean-Jacques Speyer Airbus Industrie Performance & Operations Engin. Flight Division HQ BP No. 33 31707 Blagnac Cedex, France	33 61 933002
Dr. John A. Stern Professor Psychology Washington University Box 1125 St. Louis, MO 63130	(314)889-6535
Frank Stogsdill Federal Aviation Administration 601 E. 12th Street Kansas City, MO 64106	(816)374-6941
Harty G. Stoll Boeing Commercial Airplane Co. P.O. Box 3707 MS 77-35 Seattle, WA 98124-2207	(206)237-0929
Jerry Stone McDonnell Douglas Corporation MC 202-12 3855 Lakewood Blvd. Long Beach, CA 90846	(213)593-8827
Preston Sult Boeing Commercial Airplane Co. P. O. Box 3707 MS 2T-61 Seattle, WA 98124-2207	(206)655-3789
Capt. Frank Tullo Program Manager Cockpit Resources Management Continental Airlines, Inc. 7300 World Way West Los Angeles, CA 90009-2044	(213)646-5822
Dr. Joseph P. Tymczyszyn Boeing Commercial Airplane Co. P.O. Box 3707 MS 66-25 Seattle, WA 98124-2207	(206)237-7277

James E. Veitengruber (206)342-3700
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 01-82
Seattle, WA 98124-2207

Larry Walrath (314)234-8682
McDonnell Douglas Corporation
Building 107 MS 10
P.O. Box 516
St. Louis, MO 63166

Antoinette R. Williams (408)720-5017
NASA-Ames Research Center
Bldg. 257-1
Moffet Field, CA 94035

Dr. Ken Williams (818)887-1394
McDonnell Douglas Corporation
MC 209-01
3855 Lakewood Blvd.
Long Beach, CA 90846

Brien Wygle (206)655-1400
Boeing Commercial Airplane Co.
P.O. Box 3707 MS 24-10
Seattle, WA 98124-2207

Angelos Xidias (206)431-2134
FAA ANM-111
17900 Pacific Highway South
C-68966
Seattle, WA 98168

Capt. Carl H. Young (305)873-7060
Manager Flight Test, Bldg 30, MIAFR
Eastern Airlines Inc.
International Airport
Miami, FL 33148-0001

Mike Zielinski (206)431-2205
Federal Aviation Administration
ANM-111
17900 Pacific Highway South
C-68966
Seattle, WA 98168

USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS: PART-TASK SIMULATION DATA SUMMARY WORKSHOP

PROGRAM - WORKSHOP #2
September 15 and 16, 1987

DAY 1

TIME	EVENT
CARLSBAD ROOM	
08:30-09:00 am	Registration (Continental breakfast available) (Nancy Whitman)
09:00-09:10 am	Welcome from USAF sponsor (Harry Britten-Austin)
09:10-09:30 am	Welcome/opening remarks from Boeing (Brien Wygle- Vice President Flight Operations)
09:30-09:40 am	Workshop objective (George Boucek)
09:40-10:10 am	Opening remarks from FAA sponsor (Pete Hwoschinsky)
10:10-10:40 am	Program overview: Validity, reliability criteria for the selection of measures (Mike Biferno)
10:40-11:00 am	Break
11:00-11:20 am	Application of data (George Boucek)
11:20-11:50 am	Description of part-task simulation (Diane Sandry-Garza)
11:50-01:00 pm	Luncheon

PROGRAM - WORKSHOP #2
September 15 and 16, 1987

DAY 1 (Continued)

TIME	EVENT
CARLSBAD ROOM	
01:00-01:40 pm	Subjective workload measurement: A review of the data regarding validity, reliability, applicability (Bill Corwin)
01:40-02:20 pm	Physiological workload measurement: A review of the data regarding validity, reliability, applicability (Sam Metalis)
02:20-02:40 pm	Break
02:40-03:20 pm	Performance workload measurement: A review of the data regarding validity, reliability, applicability (Bill Corwin)
03:20-04:00 pm	Analytical workload assessment: A description of the TLA task and a review of the data (Aileen Logan)
04:00-05:00 pm	Question/Answer Session (George Boucek, Mike Biferno)
05:00 pm	Adjourn
06:00 pm	Regroup in lobby for bus to Fisherman's Terminal (evening includes a cruise and dinner buffet)
10:00 pm	Return to Crowne Plaza

USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS: PART-TASK SIMULATION DATA SUMMARY WORKSHOP

PROGRAM - WORKSHOP #2
September 15 and 16, 1987

DAY 2

TIME	EVENT
CARLSBAD ROOM	
08:30-09:00 am	Continental breakfast available
09:00-10:30 am	Comparisons of workload measures (Panel)
10:30-10:50 am	Break
10:50-11:20 am	Description of full mission simulation (Diane Sandry-Garza, Bill Corwin)
11:20-12:20 am	Discussion of full mission simulation (George Boucek, Mike Biferno)
12:20-12:30 pm	Concluding remarks (George Boucek, Mike Biferno)
12:30 pm	Luncheon Buffet

WELCOME AND OPENING REMARKS FROM THE USAF

Sqn. Ldr. HARRY BRITTEN-AUSTIN

Wright-Patterson Air Force Base

Edited Transcript

Good morning Ladies and Gentlemen, welcome to the second Workshop of this Crew Workload Measurement program. It's nice to see so many of you made it here. We obviously gave you a good time at the first workshop. Many of you worked very hard at that first workshop, and I hope you're going to be pleased with the results you'll see today and tomorrow which are a direct consequence of your efforts in Long Beach in February. In addition to those who attended in February, we have many user groups represented here today because we feel the flavor of the program has now drifted toward implementation of the measurement techniques. I'm pleased to see so many representatives from the FAA, APA, ALPA, ATA, from NASA, the academic community, and even from overseas.

I've just been asked to introduce the key players in the program. First, my co-sponsor from the FAA, Pete Hwoschinsky, and the two people who manage the contract, Mike Biferno from Douglas Aircraft and George Boucek from The Boeing Company.

I think you'll find it an interesting couple of days. We have some special diversion planned for you as well. This evening's cruise promises to be very entertaining. We were well looked after at the social last night, and we're hoping you'll have two very pleasant days here. Thank you.

WELCOME AND OPENING REMARKS FROM THE BOEING COMPANY

BRIEN WYGLE

Vice-President Flight Operations
Boeing Commercial Airplane Company

Edited Transcript

I'd like to welcome everyone to Seattle from The Boeing Company. I went to the cocktail party last night and enjoyed it very much. I hope you all have a good stay. Since we've had a very dry summer, and we knew you'd like it wet in Seattle like it's supposed to be, we've even provided rain.

I'm flattered to be asked to address this erudite gathering on the subject of workload. We have been dealing with the subject now for a very long time. We owe thanks to the SAE S-7 committee, for example, and many other organizations and engineering designers for providing us with todays cockpits. Certainly we have come a long way.

I think the reason we have such good attendance and why this is an important session is, in fact, because today you are where the action is. What you're doing now is what's important. We have learned a lot over the years, but the study of workload and human factors and their role in preventing accidents is certainly a wave of the future. That is what we must devote ourselves to, perhaps in a more informed and less hysterical manner, than in the past.

In presenting accident statistics there is always a classic slide which shows that accidents occur most often in approach and landing. I want to point out, however, that we mustn't make too many early assumptions. I will refer to two fairly recent accidents.

First, the 747 accident in Japan, one of the most tragic and terrible accidents of all times, was not due to the crew's failure. There was little the crew could do to save themselves. Certainly one of the most terrifying things to a pilot outside of in-flight fire, is to be left with a hydraulically controlled airplane with no hydraulics to control surfaces. That accident nonetheless was due to human failure. The original problem was an improper repair done to the rear bulkhead which resulted in material failure. It is a long and complex story of a series of minor human errors which led to fatigue failure and a catastrophic accident. To trace and correct those things is very complicated because it's not just human failure and its not just the engineering of the job. We have to see why people fail, why this accident was not prevented.

The second is the more recent MD-80 accident in which it appears, although I don't like to second guess the NTSB, that the flaps were not extended. It has been suggested that there was no warning horn, and I suppose that we've learned to depend on those warning horns to tell us that we're configured for take off. There are only a few things that you have to be certain about during take off.

One is your flaps. Nonetheless, if the horn had been pulled by the circuit breaker, because we've all seen warning horns silenced, we have to ask ourselves why the crew would do that. We must not just talk to the crew and tell them not to pull the circuit breaker. We have to look at "why" they pulled it. Where in our design did we permit that to occur? That's the thing that the designers are asking themselves every day.

I would like to tell you a little about a study done at The Boeing Company recently by two of our engineers, Les Lautman and Peter Gallimore (included in this mailing is a complete copy of this study). They noted that in line with Pareto's thinking and Pareto's charts, 15% of the world's airlines had 80% of the accidents and 80% of the airlines had no accidents. They took a recent 10 year period and looked at Boeing customers only. They thought we should be working on the concentration of where the accidents are. That's a little difficult to do however. It's not the manufacturer's job to tell the airlines how to prevent accidents, and manufacturer's are not too well received when they attempt to do so. Lautman and Gallimore decided to visit the airlines that traditionally don't have accidents to see what those airlines did in flight operations. I'm sure there's room for significant statistical error, but they came up with a representative number of airlines, both domestic and international, that had good safety records. They asked those airlines what they did in flight operations, and listed all these things to see what these airlines did in common. Not surprisingly, the airlines had a great deal in common.

First, they had a well organized and disciplined flight operations department. They had people who were paying full-time attention to the administration of the department. They had a corporate attitude of flight safety, because we know if your trying to run a flight operations department and you can't get the budget you need from the president and the chief financial officer , you cannot provide the needs for a safe flight operations. In all cases the corporate management was safety conscious. There was sufficient response from the bean counters and other non-flying people that they recognized the needs and provided the means to have a safe flight operation.

Another factor in common was the concept of standardization pilots. That is, there was a pilot assigned to be the standardization pilot. He would see that all the flight crews were using the same procedures. They had a check-airman program where the line pilot was continually checked, in many cases beyond the governmental requirements. They had mandatory briefings before takeoff and before approach. This was a procedure pilots had to go through no matter how routine it seemed. The pilot was required to brief before take off and before approach, including the missed approach. It is this discipline, we believe, that contributes to their safety.

Another common factor among these airlines was that they all owned their own simulators. They did very little contract training. If they had a small fleet of a certain type of aircraft that didn't justify a simulator, they might contract with someone else, but they would send their own instructors and would use their own procedures. They developed standardized approaches with the same procedures for callouts, the same requirements for a stabilized approach - on speed, on glide slope and so on. Each of these companies tightly controlled the cockpit procedures and the cockpit language. There was no room for casual language usage. The crew had to call everything by its right name. The training was extensive, in many cases more than the requirements. Most often these airlines used the LOFT concept of line oriented flight training.

It has been my experience that most of the things I've mentioned tend to be missing or improperly applied in those airlines that have a bad safety record. I'm sure my friend Mr. Knickerbocker from Douglas Aircraft would agree from his observation of customer operations. We know, in fact, how to create a safe airline. It is not always done however, for many reasons.

I believe the modern cockpit to be a very good one. I think starting with the 757/767 and A310, to be followed by the MD-80 advanced and 737 advanced cockpits and followed by the A320, MD11 and 747-400, these cockpits are really very much the same idea. There are detail differences but everyone has a similar concept of what a modern cockpit is. I think we would all agree that the three man cockpit is an out of date and unsatisfactory cockpit in the world today. That was certainly controversial, but once put to bed that idea has swept widely across the industry. In fact two men make an ideal human relation combination to operate an airplane.

There is criticism of the cockpits today, that we have provided an environment where the pilot may become overly complacent and not be sufficiently motivated to do the job properly, resulting in errors. There may very well be justification for this. However, there are other times when the pilot sees no evidence of insufficient workload. For instance, when the pilot gets an approach change at the last minute and is making inputs into his flight management computer, I think those are times when he is quite heavily loaded. Certainly, if we can simplify the number of keystrokes required to input an approach change, that would be a valuable improvement. Of course, people are working on that. We certainly have to address the subject of workload; where it is high and where it isn't sufficiently high. The idea of keeping people alert is an important one.

The concept of fatigue is also important. None of us work very well when we're on the verge of falling asleep. The fatigue problem is a very difficult one to approach. No matter how complicated we make our duty time allowables, we're never going to really know the state of that pilot when he gets into the airplane. We assume if a pilot leaves at 9 o'clock in the morning and is bright and rested and in good shape, he can fly a long time. I suppose that's generally true, but we know that sometimes people have a bad night, or sometimes they have mental stress. We also know that some pilots who take off at 6 o'clock in the evening are very fresh because they're those lucky people who can lay down and sleep 4 hours in the afternoon. Not all of us can do that. So we really don't know the state of the pilot when he gets into the cockpit. We really don't know what an individual's mental and physical state will permit him to do on that particular day. I certainly don't know how to measure that, but perhaps it's food for thought.

Finally, I would like to comment on the commitment of The Boeing Company to this particular group and to the subject of workload and human factors in general. We have combined our pilots, engineers and human factors people into a group that is jointly responsible for the development of flight decks. We are committed to flight deck improvement from both a working environment and a safety point of view. I think we have made that commitment, and it is clear to me that our colleagues at Douglas and Aerospatiale have made similar commitments. There's no doubt that the industry today is working hand in glove with the government, with airlines, with others, to provide the kind of cockpit we feel is correct.

I am very impressed to see both the number and the qualifications of the people who have attended this workshop. I would like to complement Joe Tymczyscyn, Diane Sandry-Garza, and Aileen Logan and the staff who have prepared for this workshop, and I hope and trust that you will have both a pleasant and useful stay. Thank you.

USAF / FAA Review of Workload Measurement Methods: Part-Task Simulation Data Summary Workshop

Objectives

B1163.01

- Describe the technical approach to the part-task simulation
- Review results of part-task simulation
- Gather input on the results
- Describe the technical approach to the full-mission simulation
- Gather input on the simulation approach

B1163.02

OPENING REMARKS FROM FAA SPONSOR

Peter V. Hwoschinsky

September 15, 1987

Good morning ladies and gentlemen, I would like to reaffirm the welcome from our contractors, and thank all of you for taking your valuable time to attend this workshop and assist us in providing support to you in minimum flightcrew determination.

Let me take a few moments to inform you how this project is organized, who is involved, and how what we do will be used. First of all, regional requirements are recognized by the office of Aviation Standards in Washington. They are prioritized and then given to the appropriate R&D office for action.

The Cockpit Technology Program Office (for whom I work) was asked to develop this project in response to Aviation Standards and to the President's Commission on Crew Complement. Several (14) of the recommendations therein referred to developing and implementing improved methods of measuring aircrew workload. Simultaneously, the FAA Northwest Mountain Region developed a draft advisory circular on minimum flight crew requirements (AC 25.1523), which has been circulated for comment. In order to provide guidance materials for evaluating compliance with this circular, we developed a project to document existing methods of workload measurement, to organize and catalogue promising new techniques, and to test a representative sample of each type of physiological, subjective, and performance related measures. We did this through a seed money contract from our Interagency Agreement with the Air Force to take advantage of existing expertise and manufacturers' experience. The Douglas and Boeing Companies have agreed to share part of the burden of this effort through in house support.

At the first workload workshop which we held last February, we asked an assemblage of experts (many of whom are here today) to review a rather lengthy list of workload measures and recommend to us which ones we should consider for testing and inclusion in the Advisory Circular. At the conclusion of the part task and full mission simulations and our evaluation thereof, we will provide a report to the Northwest Mountain Region Aircraft Certification Directorate and Aircraft Evaluation Groups; and FAA Headquarters Flight Standards with our recommendations.

Most of you here today already have a good working knowledge of what workload measurement is, and how it is used in design. However, on the certification side, we have engineers and certification specialists who are expert pilots who use that expertise to evaluate, by comparison, the proposed new systems and cockpit suites during all phases of design, development and production. Our intention in the project is to provide additional means for those specialists to gain an understanding of the workload demands of any new design. We have no intention of replacing the existing well proven and highly successful means of subjective assessment. We see this effort as an adjunct to the existing system when the advisory circular is published in final form. The certification process will continue as before with the addition of looking at manufacturers' documentation of acceptable means of objective workload assessment as outlined in the AC. Once we have made our report to Flight Standards, our portion of the project will be complete.

However, we feel strongly that our findings should be validated through flight test verification. Some follow on R&D should be performed to evaluate advanced techniques, and to provide a method or means of including new techniques into the AC as appropriate.

Finally, the results which we will have gathered for FAR part 25 aircraft should be adapted for use with FAR part 23 certification use, since it is generally conceded that single pilot IFR flight in a small plane can be one of the most demanding taskloads.

I will let Douglas and Boeing contractors fill you in on the details of our project. George Boucek has given you our objectives. Now Mike Biferno will give you a program overview.

Thank you.

ASSESSMENT OF CREW WORKLOAD MEASUREMENT

METHODS, TECHNIQUES, AND PROCEDURES

PROGRAM OVERVIEW

VALIDITY AND RELIABILITY CONSIDERATIONS

PROGRAM OBJECTIVE

PROVIDE GUIDELINES FOR SELECTING WORKLOAD MEASURES WHICH ARE VALID, RELIABLE, AND APPLICABLE FOR AIRCRAFT CERTIFICATION.

- FLEXIBLE BASIS FOR SELECTING MEASURES
- ENABLE FAA TO EVALUATE WORKLOAD MEASUREMENT PLANS

PROGRAM SCOPE

IDENTIFY EXISTING CANDIDATE WORKLOAD MEASURES

SELECT THE MOST VALID, RELIABLE, AND APPLICABLE MEASURES FOR TESTING

- o INITIAL SCREENING WITH LITERATURE REVIEW AND WORKSHOP #1
- o FINAL SCREENING IN PART-TASK SIMULATION
- o SUITABLE FOR FULL-MISSION SIMULATION OR IN-FLIGHT

EVALUATE COMMERCIAL TRANSPORT ENVIRONMENT

DEVELOP LIST OF ACCEPTABLE WORKLOAD MEASURES

DEMONSTRATE THE PROCESS OF WORKLOAD MEASURE SELECTION

APPROACH

IDENTIFY CANDIDATE MEASURES

DETERMINE BEST MEASURES

PROVIDE GUIDELINES FOR MEASURE SELECTION

IDENTIFY CANDIDATE MEASURES

IDENTIFY SELECTION CRITERIA

CONDUCT LITERATURE REVIEW

DEVELOP FACT MATRICES

CONDUCT FIRST WORKSHOP

DETERMINE LIST OF MEASURES FOR TESTING

LIST OF MEASURES FOR TESTING IN PART-TASK SIMULATION

SUBJECTIVE	PERFORMANCE	PHYSIOLOGICAL
TLX	CONTROL ACTIVITY	HEART
SWAT	WHEEL COLUMN PEDAL	RATE RATE VARIABILITY
1-20 OVERALL		
	SECONDARY TASK	HR SPECTRAL ANALYSIS
	RESPONSE TIME ERROR	BLOOD PRESSURE RESPIRATION
		EYEBLINK

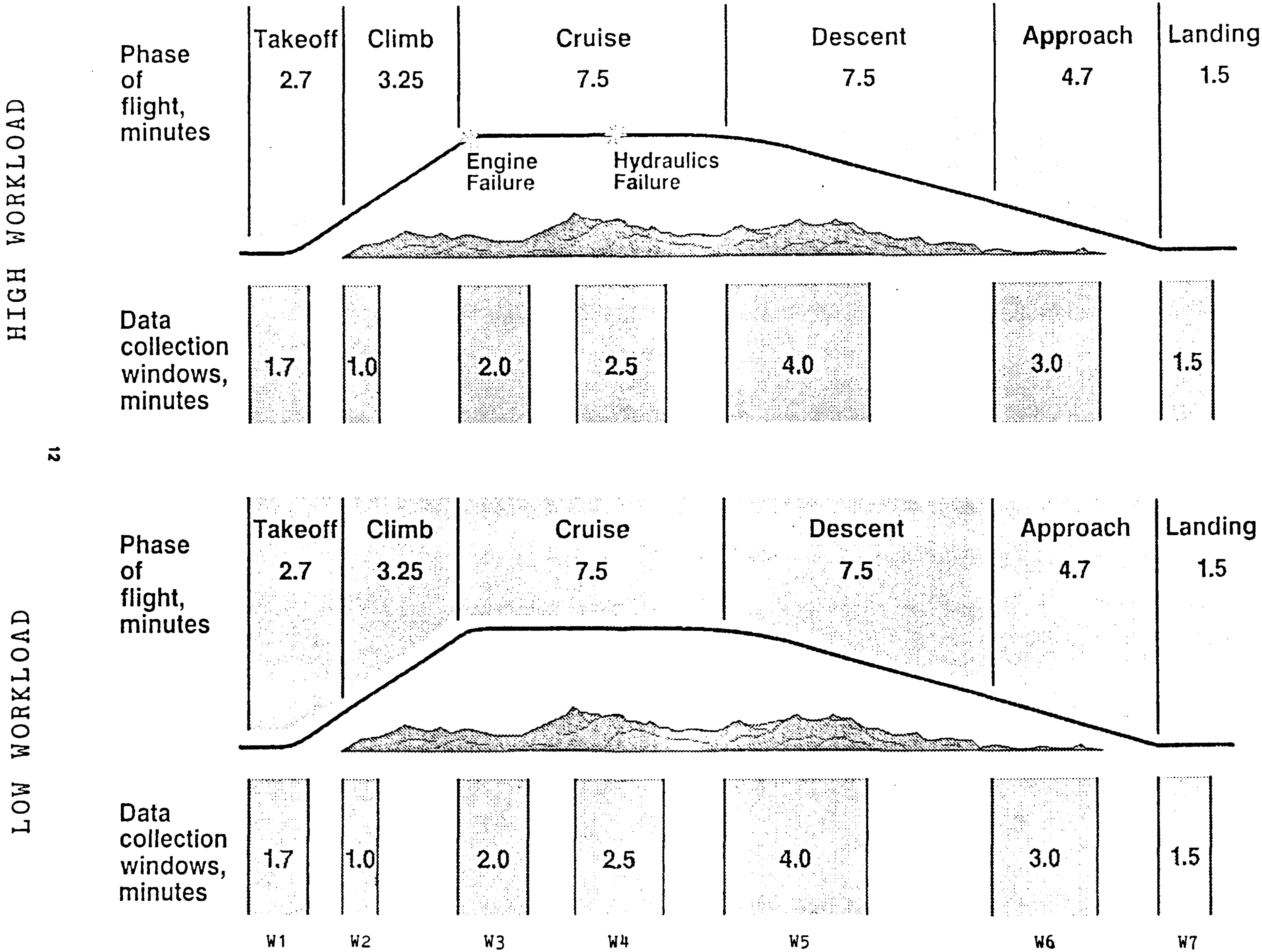
DETERMINE BEST MEASURES

PERFORM PART-TASK SIMULATION TESTING

CONDUCT SECOND WORKSHOP

PERFORM FULL-MISSION SIMULATION TESTING

DEVELOP LIST OF ACCEPTABLE WORKLOAD MEASURES



HIGH WORKLOAD
Phase of flight, minutes
Takeoff 2.7
Climb 3.25
Cruise 7.5
Descent 7.5
Approach 4.7
Landing 1.5
Engine Failure
Hydraulics Failure
Data collection windows, minutes
1.7
1.0
2.0
2.5
4.0
3.0
1.5
LOW WORKLOAD
Phase of flight, minutes
Takeoff 2.7
Climb 3.25
Cruise 7.5
Descent 7.5
Approach 4.7
Landing 1.5
Data collection windows, minutes
1.7
1.0
2.0
2.5
4.0
3.0
1.5
W1
W2
W3
W4
W5
W6
W7

PERFORM PART-TASK SIMULATION TESTING

VALIDITY: ARE YOU MEASURING WHAT YOU THINK YOU ARE MEASURING?

- ARE RELEVANT TYPES OF WORKLOAD EXAMINED? **(CONTENT)**
- DOES MEASURE CHANGE WHEN WORKLOAD IS VARIED? **(CONSTRUCT)**
- DOES MEASURE AGREE WITH TIME-LINE ANALYSIS? **(CRITERION-RELATED)**

RELIABILITY: HOW STABLE IS THE MEASURE?

- DOES MEASURE YIELD SAME RESULT WITH SAME PILOT? **(TEST-RETEST)**
- DOES MEASURE YIELD SAME RESULT WITH DIFFERENT PILOTS? **(INTER-RATER)**

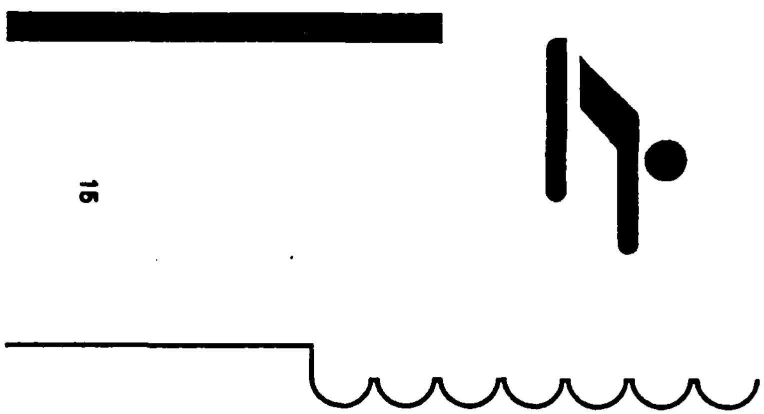
TEST-RETEST RELIABILITY

(EXAMPLE: 100-METER DASH IN SECONDS)

	HIGH RELIABILITY		LOW RELIABILITY	
ATHLETE	TEST	RETEST	TEST	RETEST
1	10	9.5	10	11
2	10.5	10	10.5	10.5
3	11	10.5	11	9.5
4	11.5	11	11.5	12
5	12	11.5	12	10
6	12.5	12	12.5	11.5
	$r = 1.0$		$r = 0.2$	

CA1449.14

INTER-RATER RELIABILITY
(Example: Platform Dive)



Low Reliability

Judge	1	2	3	4	5
	8.2	9.7	8.4	8.1	6.0

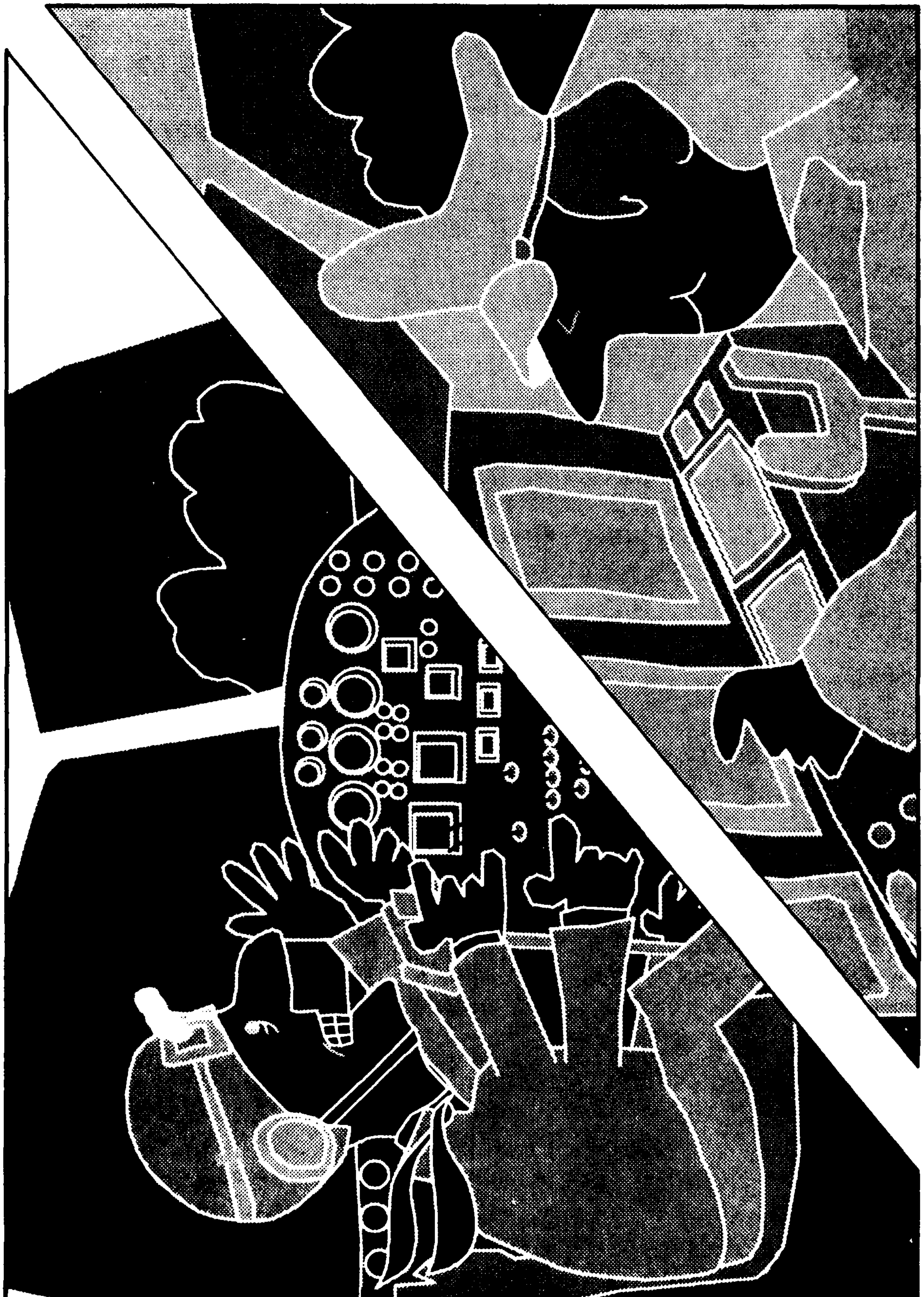
High Reliability

Judge	1	2	3	4	5
	8.2	8.3	8.4	8.1	8.4

CA1449.02

Application of Data

B1163.03



Practicality

- Costs incurred
- Time contraints
- Equipment constraints

A1163.02

Costs Incurred

- Equipment costs
- Installation and preparation costs
- Time and schedule impact
- Flight and simulation costs
- Documentation costs

A1163.09

Time Constraints

- Certification program schedule
- Production schedules
- *Delivery schedules*

A1163.07

Equipment Constraints

- Limited hardware space
- Limited panel space
- Large distance between pilot and data collection hardware
- Potential signal interference
- Inability to change flight deck configuration

A1163.08

Applicability

- Environmental considerations
- Pilot acceptance
- Certification considerations

A1163.03

Environmental Considerations

- Must be capable of gathering data under the constraints of the flight environment

  - Part-task simulation
  - Full mission simulation
  - Flight test

- Will be applied to multidimensional task demands that could include unpredictable variations

A1163.04

Pilot Acceptance

- Nonintrusive to flight task
- Compatible with flight safety
- Compatible with normal methods of operation
- Responsive to crew self-image
- Noncareer threatening

A1163.06

Certification Considerations

- Minimal interference with other certification flight test activities
- Technique should be appropriate for the specific phase and objectives of the certification program
- Initial efforts concentrate on those aspects that have changed from the reference aircraft

A1163.05

Workload Factors

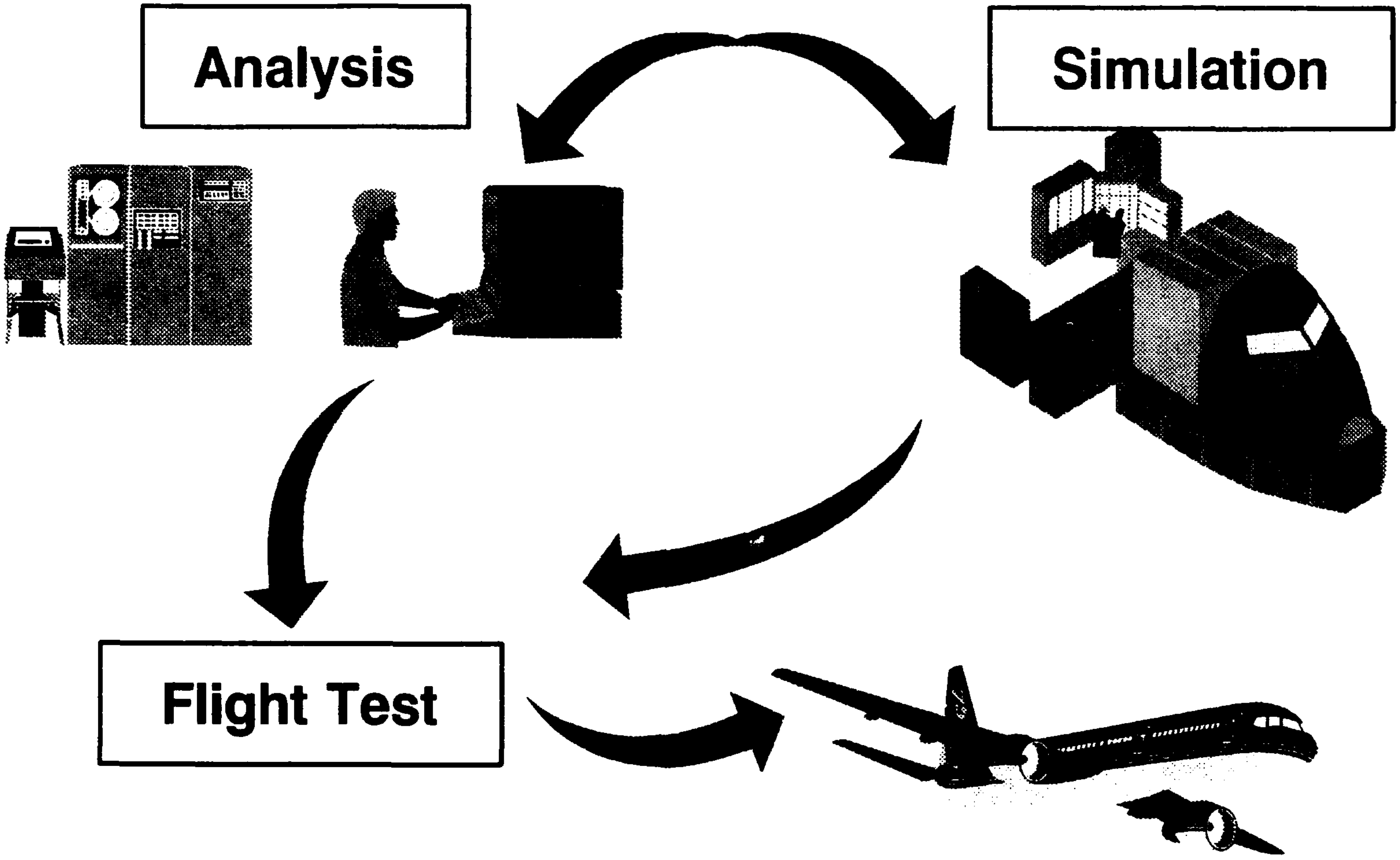
FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
8. Communication and navigation

9. Nonnormals
6. Crew member out of area
7. Automation breakdown
10. Incapacitated crew member

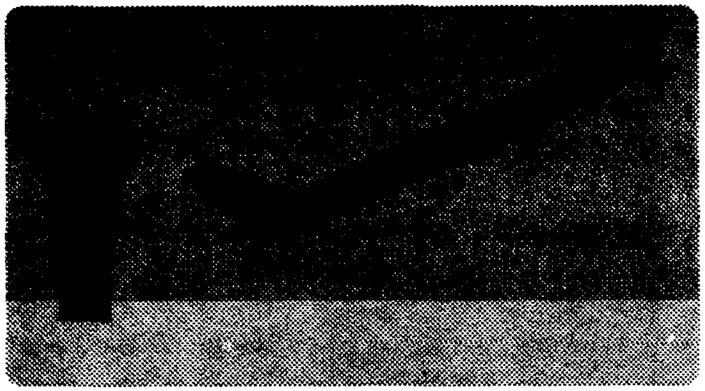
A1167.08

Crew Workload Assessment

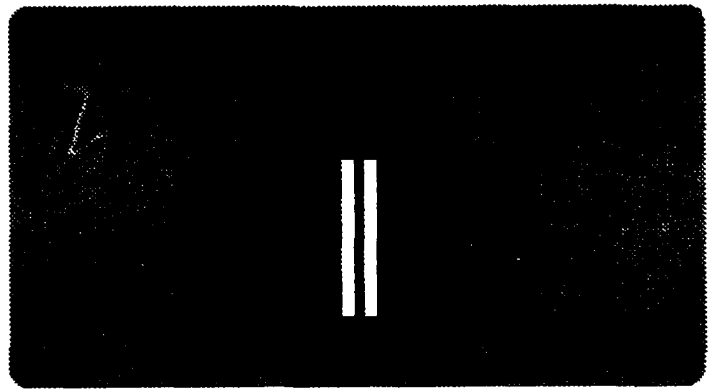


Measurement Considerations

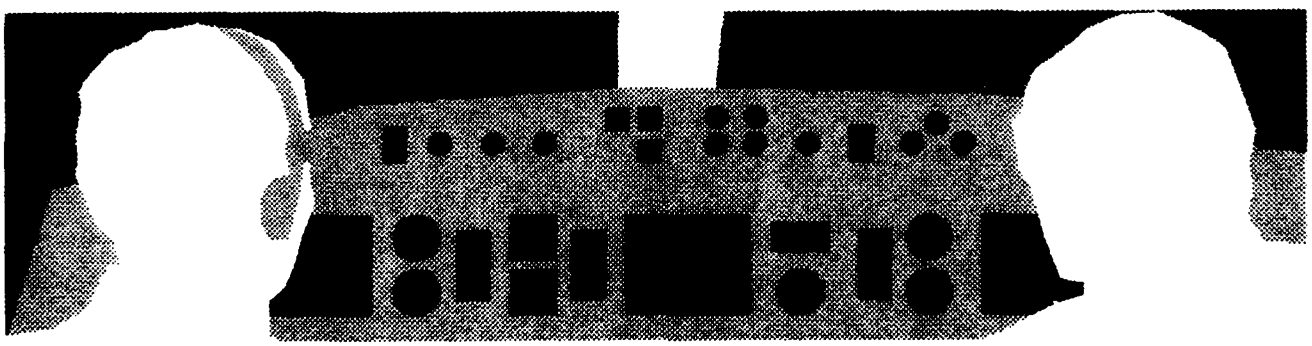
Safety



Economics



Crew Acceptance



A1183.11

- Objective of the program to identify assessment or measurment techniques that reliably discriminate changes in workload
- Data from testing used to evaluate discrimination rather than to obtain absolute values of workload
- No intention to look for "red line" values for either overload or underload

B1163.04

Description of Part-Task Simulation Testing

Diane L. Sandry-Garza
Boeing Commercial Airplane Company
Seattle, Washington

C1167.01

Simulation Facility

- NASA - Ames (MVSRF)
- Boeing 727 motion-base simulator
- High level of fidelity
- ATC simulation

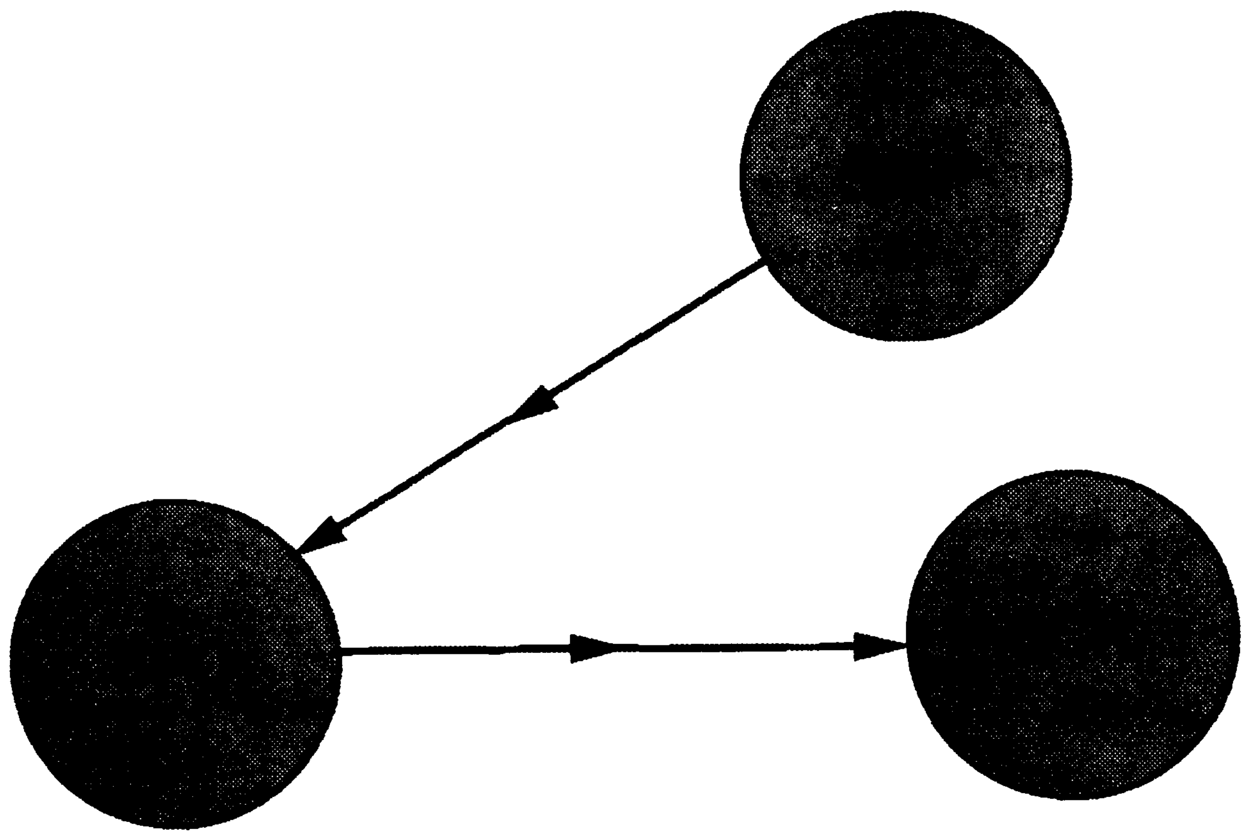
A1167.01

Subjects

- FAR qualified and current 727 airline pilots
- Captain (data collection)
- Confederates
- Representative of population

A1167.02

Simulation Scenarios



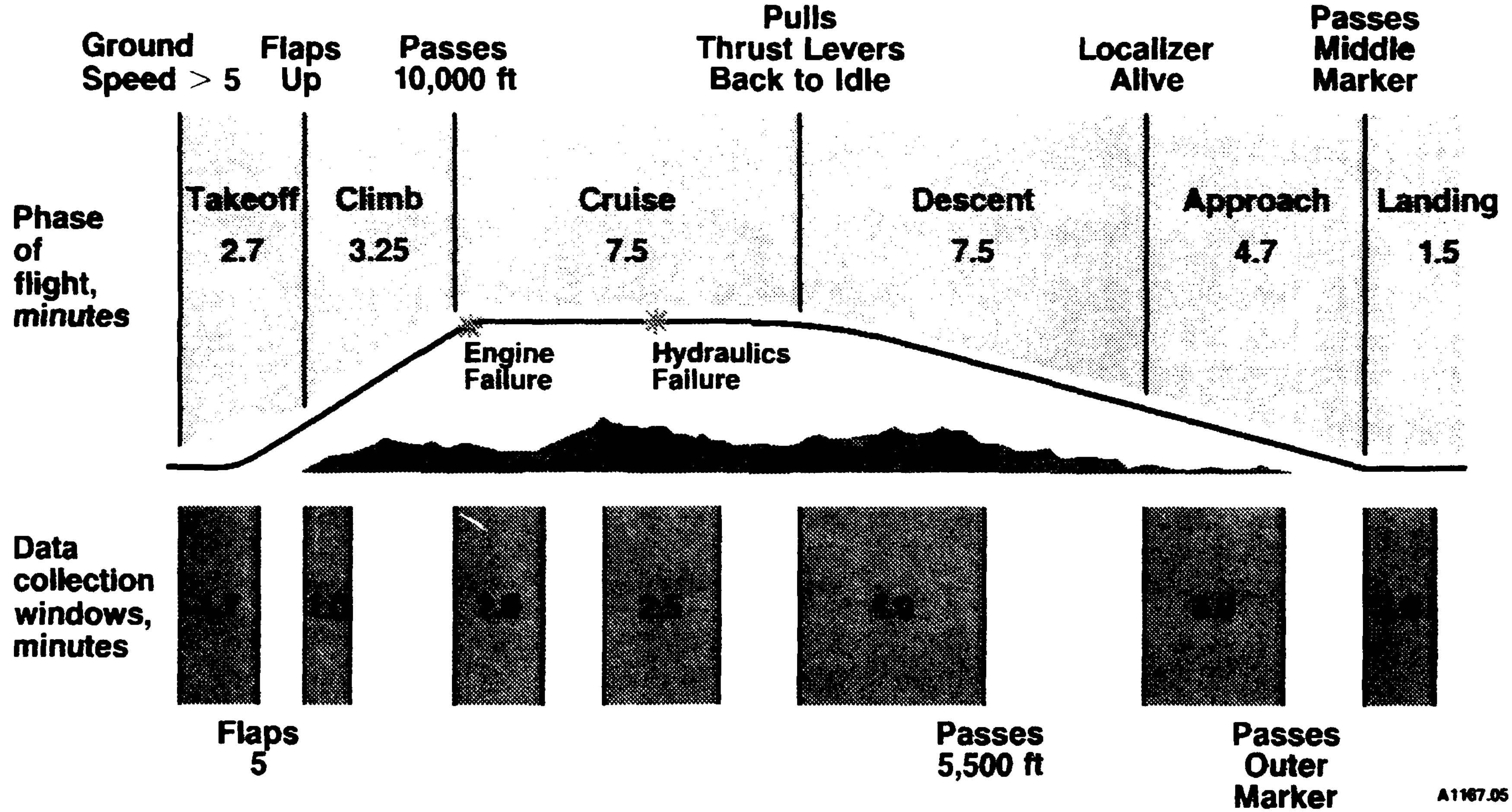
A1167.03

Two Workload Levels

Conditions	Level	
	High	Low
Weather	Ceiling, 500 ft; visibility, 1 mi	Clear
Wind	12 kn at takeoff and landing	5 kn at takeoff and landing
Autopilot	Inoperative	Operating
Turbulence	Significant	Minimal
Nonnormals	• Number three engine stall • Hydraulic System B failure • Distractors (i.e., autopressure failure, window overheat)	None

A1167.04

Phases of Flight and Data Collection



Part-Task Simulation

	Data Collection Windows	
Flight Phase	Open Measurement Window	Close Measurement Window
Takeoff	Ground speed $>$ 5	Flaps 5
Climb	Flaps up	1 min later
Cruise 1	10,000 ft	2 min later
Cruise 2	3 min after 10,000 ft	2 1/2 min later
Descent	Throttles to idle	5,500 ft
Approach	Localizer activation	Outer marker
Touchdown	Middle marker	1 1/2 min later

D1167.04

Operationally Relevant Types of Workload

FAR 25.1523, Appendix D

- FAA addresses
  - 6 workload functions
  - 10 workload factors
- Map FAR-25 function and factor descriptions into scenarios
- Divide scenarios into high and low workload levels based on objective task demands

A1167.06

Basic Workload Functions
FAR-25

1. Flightpath control
2. Collision avoidance
3. Navigation
4. Communications
5. Operations and monitoring of aircraft engines and systems
6. Command decisions

A1167.07

Workload Factors

FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
8. Communication and navigation

9. Nonnormals
6. Crew member out of area
7. Automation breakdown
10. Incapacitated crew member

A1167.06

Function and Factor Mapping

Example

Function	Factor	00:02:15 Gear Retract - Start Initial Climb
4,5,6	3,8A	• Calls, “gear up”
4	8A	• Hears F/O, “gear up”
5	5	• Sees F/O compliance (peripheral vision)
1,5	2,3,5	• Looks to see if airspeed stabilized at approximately V2 + 10
1,5,6	1,2,3	• Adjusts pitch attitude to maintain V2 + 10 if necessary
1,5,6	1,2,3	• Sets FD pitch knob to proper pitch attitude

00:02:35 Cleared Direct Sacramento Vortac

A1167.09

Part-Task Simulation

Function and Factor Tally Sheet

Flight Segment SFO ⟶ SCK

Function

1. Flightpath	1
2. Collision avoidance	2
3. Navigation	0
4. Communication	15
5. Operations and monitoring	3
6. Command decisions	2

Physical 11

Mental 50

Window Cruise 2

Factor

1. Controls	0
2. Displays	0
3. Procedures	1
4. x x x x x x x x x x x x x x	
5. Monitoring	0
8a. Communication	2
8b. Navigation	0

Non-Normals

7. Automatic	13
9(1) Control	3
9(2) Display	0
9(3) Procedure	6
9(5) Monitoring	0
9(8A) Communication	13
9(8B) Navigation	0

D1167.10

Physical/Mental Task Loadings

Measurement Window	Flight Segment: Low		High	
	SFO-SCK	SMF-SFO	SFO-SCK	SMF-SFO
Takeoff	75 / 124	71 / 117	75 / 124	71 / 117
Climb	39 / 75	38 / 78	40 / 82	39 / 95
			Autopilot Inop	
Cruise 1	13 / 46	10 / 37	34 / 128	31 / 121
			No 3 Engine Compressor Stall	
Cruise 2	1 / 6	1 / 5	11 / 50	11 / 49
			B System Hydraulics Failure	
Descent	47 / 137	45 / 141	46 / 140	53 / 164
Approach	63 / 185	66 / 199	61 / 177	64 / 190
Land	28 / 62	28 / 62	26 / 59	26 / 59
Totals	266 / 635 901	259 / 637 896	293 / 760 1053	295 / 795 1090

D1167.09

Dependent Measures

- Subjective
- Physiological
- Performance
- Task timeline analysis

A1167.11

Dependent Measures

- Subjective
  - NASA TLX
  - SWAT
- Physiological
  - Heart rate variability
  - Eye blinks
  - Eye movement
- Performance
  - Primary task
  - Secondary task
- Analytical
  - Task timeline analysis

A1167.32

Subjective Measures

- Subjective workload assessment technique (SWAT)
- Task load index (TLX)
- Overall workload score (simple 20-point scale)

B1123.04

Subjective Measures

- Inflight (direct measurement)
- Postflight (videotape)

- Example measures
  - NASA TLX
  - SWAT

A1167.12

Part-Task Simulation

Subjective Measures

In-Simulator (Four Phases)	Post-Flight Videotape (Seven Phases)
• Takeoff-Cruise • Cruise • Descent-landing • Overall	• Takeoff • Climb • Cruise 1 • Cruise 2 • Descent • Approach • Landing

D1167.15

Physiological Measures

- Eyeblink rate
- Eye movement
- Heart
  - Rate
  - Rate variability
- Heart spectral analysis
  - Blood pressure component
  - Respiration component

B1123.05

Performance Measures

- Primary Task
  - Reversals
    - Stick
    - Rudder
    - Aileron
    - Throttle
  - Approach and landing
    - Flightpath error
    - Glideslope and localizer variability
    - Altitude at outer, middle, and inner markers
- Secondary Task
  - Sternberg RT task

A1167.14

Secondary Task

- Two "flight numbers" are designated positive probes
  - Pilot's own flight number (United 247)
  - Another aircraft flight number (United 241)
- Pilot is instructed to respond as quickly and accurately as possible
- Pilot response is to toggle "push to talk" switch

B1123.06

Part-Task Simulation

Secondary Task

Captain's Memory Set:

- Airplane call sign 352 247
- Other aircraft 356 241

Designated Airline: United

D1167.16

Secondary Task Measures

- Response time
- Probe accuracy

B1123.07

Timeline Analysis (TLA)

Computes the ratio of time required to time available throughout the flight mission scenario.

A1167.31

Timeline Analysis

- Evaluates for each crew member:
  - Hand activity time
  - Eye activity time
  - Cognition time
- Estimates the times a crew member is occupied by:
  - Visual task
  - Motor task
  - Cognitive task
  - Verbal task
  - Auditory task

A1167.30

Task Timeline Analysis (TLA)

- Selected segments
- Proven TLA method
- Identifies high and low task-demand levels
- Validity of workload measures against proven tool

A1167.15

Part-Task Simulation Protocol

- Greet pilot
- Provide tape-recorded instructions and answer questions
- Provide differences training
- Subjective training

  * * Lunch * *

- Instrument pilot for physiological measures
- In-cab differences training
- Experimental runs
- Post-flight subjective measures
- Debriefing

D1167.17

Part-Task Simulation

Experimental Variables

Four factors: 2 x 2 x 4 x 7 design

Factor one: workload (two levels) low and high

Factor two: route (two levels) SFO - SCK and SMF - SFO

Factor three: four possible orders A, B, C, and D

Factor four: measurement epoch (task loadings) (seven levels)

1. Takeoff
2. Climb
3. Cruise 1
4. Cruise 2
5. Descent
6. Approach
7. Landing

D1167.11

Part-Task Simulation

Experimental Design

Session One:	SWAT Inflight	NASA/TLX Post-Flight	
Order Number: 1	2	3	4
SFO - SCK (LO) SMF - SFO (HI)	SMF - SFO (HI) SFO - SCK (LO)	SMF - SFO (LO) SFO - SCK (HI)	SFO - SCK (HI) SMF - SFO (LO)
Session Two:			
SMF - SFO (HI) SFO - SCK (LO)	SFO - SCK (LO) SMF - SFO (HI)	SFO - SCK (HI) SMF - SFO (LO)	SMF - SFO (LO) SFO - SCK (HI)
Ss 1,9,17	Ss 2,10,18	Ss 3,11	Ss 4,12

Session One:	NASA/TLX Inflight	SWAT Post-Flight	
Number: 1	2	3	4
SFO - SCK (LO) SMF - SFO (HI)	SMF - SFO (HI) SFO - SCK (LO)	SMF - SFO (LO) SFO - SCK (HI)	SFO - SCK (HI) SMF - SFO (LO)
Session Two:			
SMF - SFO (HI) SFO - SCK (LO)	SFO - SCK (LO) SMF - SFO (HI)	SFO - SCK (HI) SMF - SFO (LO)	SMF - SFO (LO) SFO - SCK (HI)
Ss 5,13	Ss 6,14	Ss 7,15,19	Ss 8,16,20

D1167.12

SUBJECTIVE MEASURES

All simulation sessions were video taped. Subjects viewed the video tapes of their flights at the end of a day's session for the purpose of subjective rating. Half of the subjects used the Subjective Workload Assessment Technique (SWAT) and the other half used the NASA Task Load Index (TLX).

Both measures, SWAT and TLX, could discriminate the predicted difference in workload. Both measures showed high INTER-RATER reliability as well. The measures were highly correlated, r=.97, indicating that the measures are tapping the same underlying phenomena.

On the transparencies dots are used to denote a statistically significant relationship.

- o On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.
- o On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

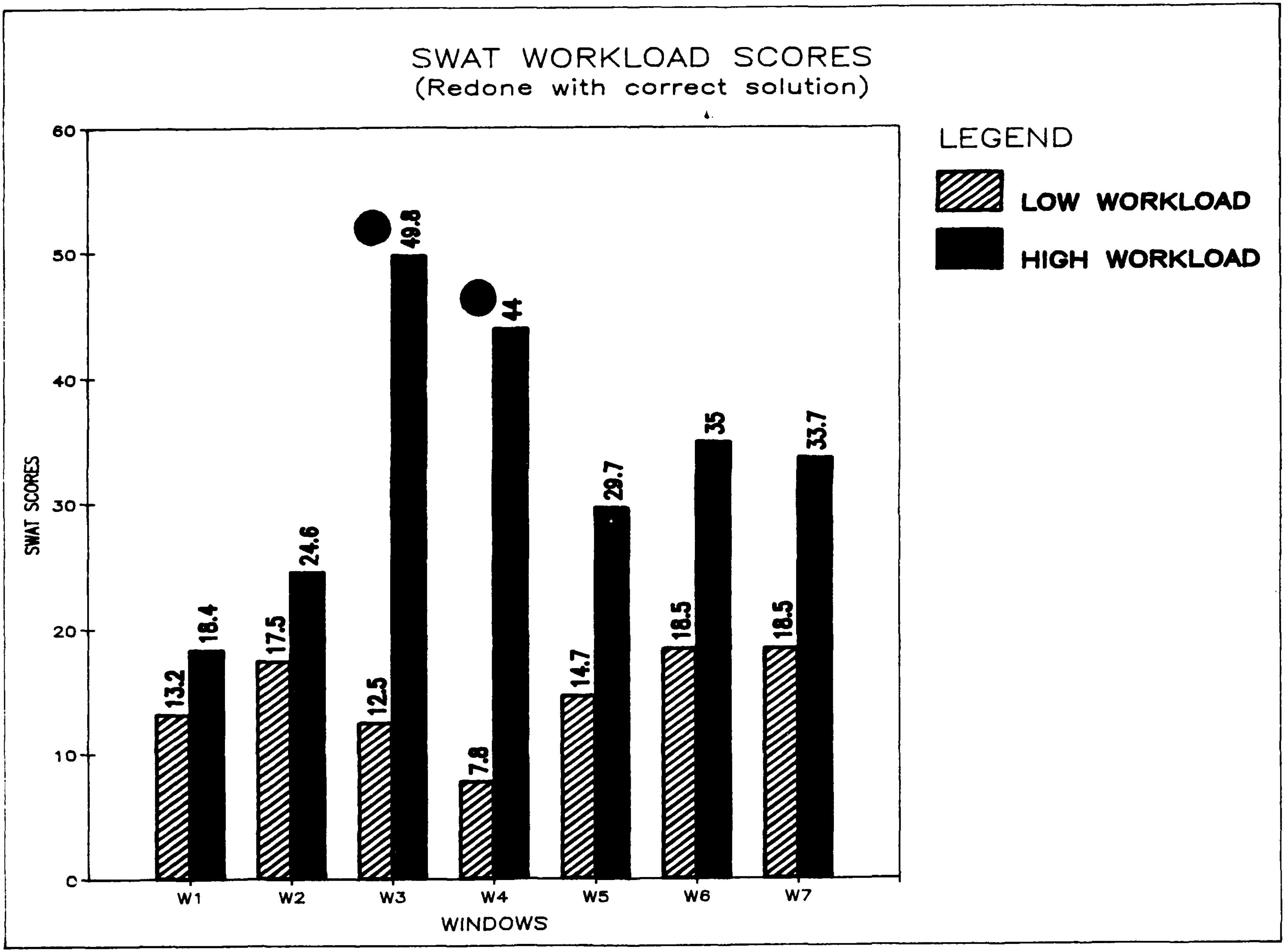
Following are the transparencies presented on the analysis of the subjective measures data.

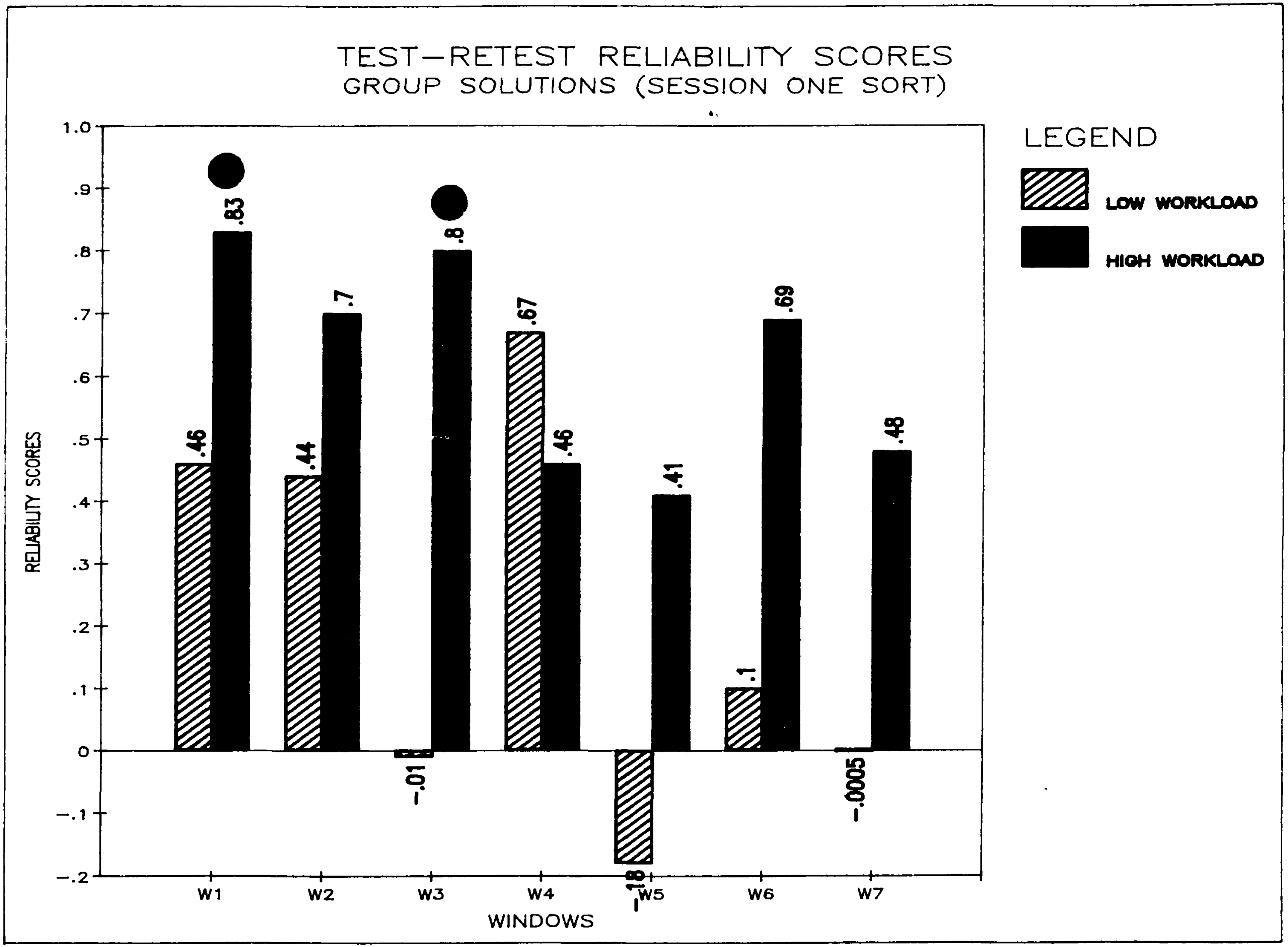
SUBJECTIVE MEASURES

- SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)
- TASK LOAD INDEX (TLX)
- OVERALL WORKLOAD SCORE (SIMPLE 20—POINT SCALE)

SUBJECTIVE WORKLOAD ASSESSMENT TECHNIQUE (SWAT)

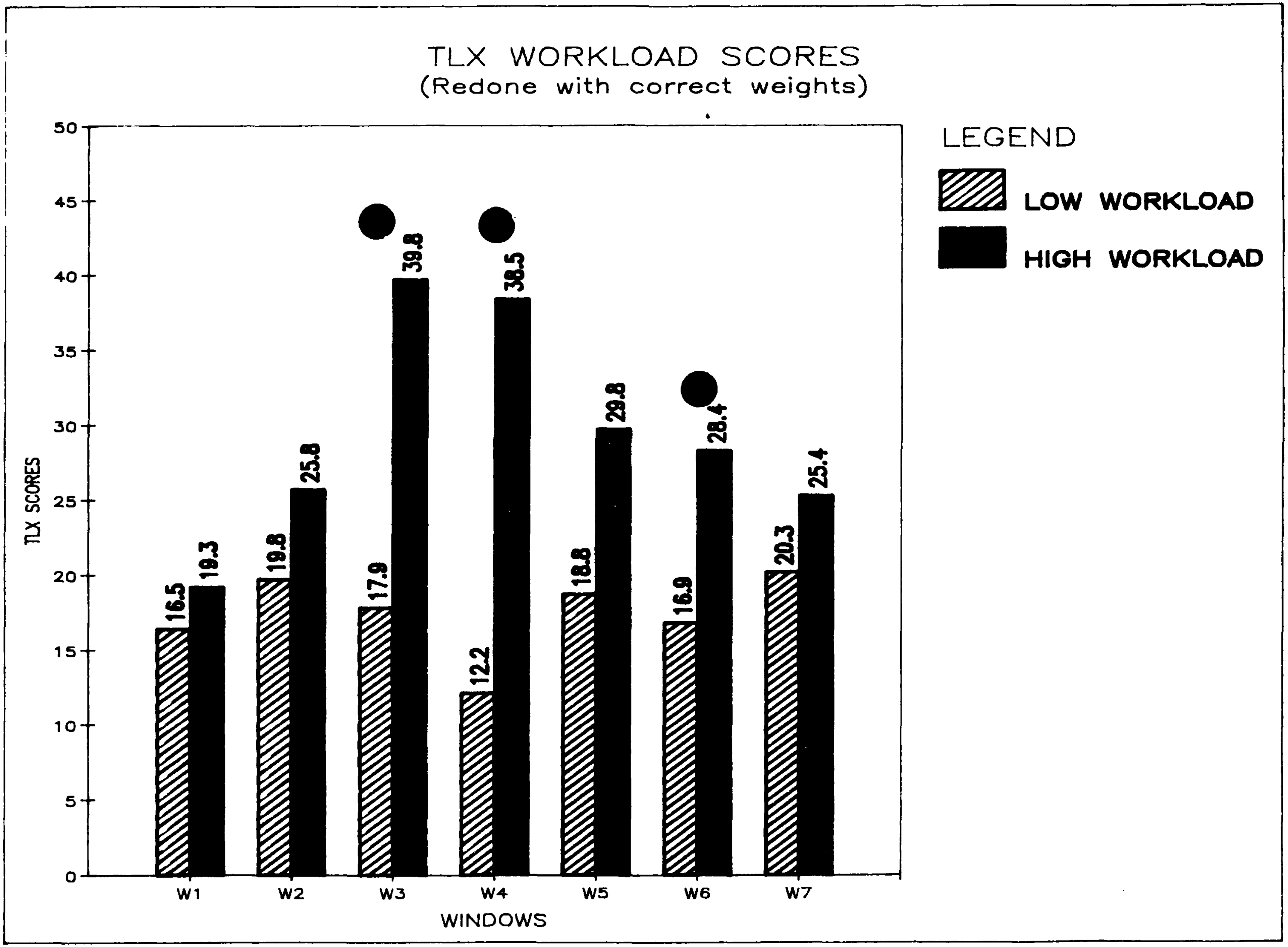
- 3 BIPOLAR SCALES (TIME, MENTAL EFFORT, STRESS)
- 3 POSSIBLE RATING VALUES FOR EACH RATING SCALE
- USES CONJOINT MEASUREMENT THEORY
- YIELDS SINGLE WORKLOAD SCORE WITH VALUE BETWEEN 0 – 100


SWAT WORKLOAD SCORES
(Redone with correct solution)
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
SWAT SCORES
0
10
20
30
40
50
60
W1
W2
W3
W4
W5
W6
W7
WINDOWS
13.2
18.4
17.5
24.6
12.5
49.8
7.8
44
14.7
29.7
18.5
35
18.5
33.7

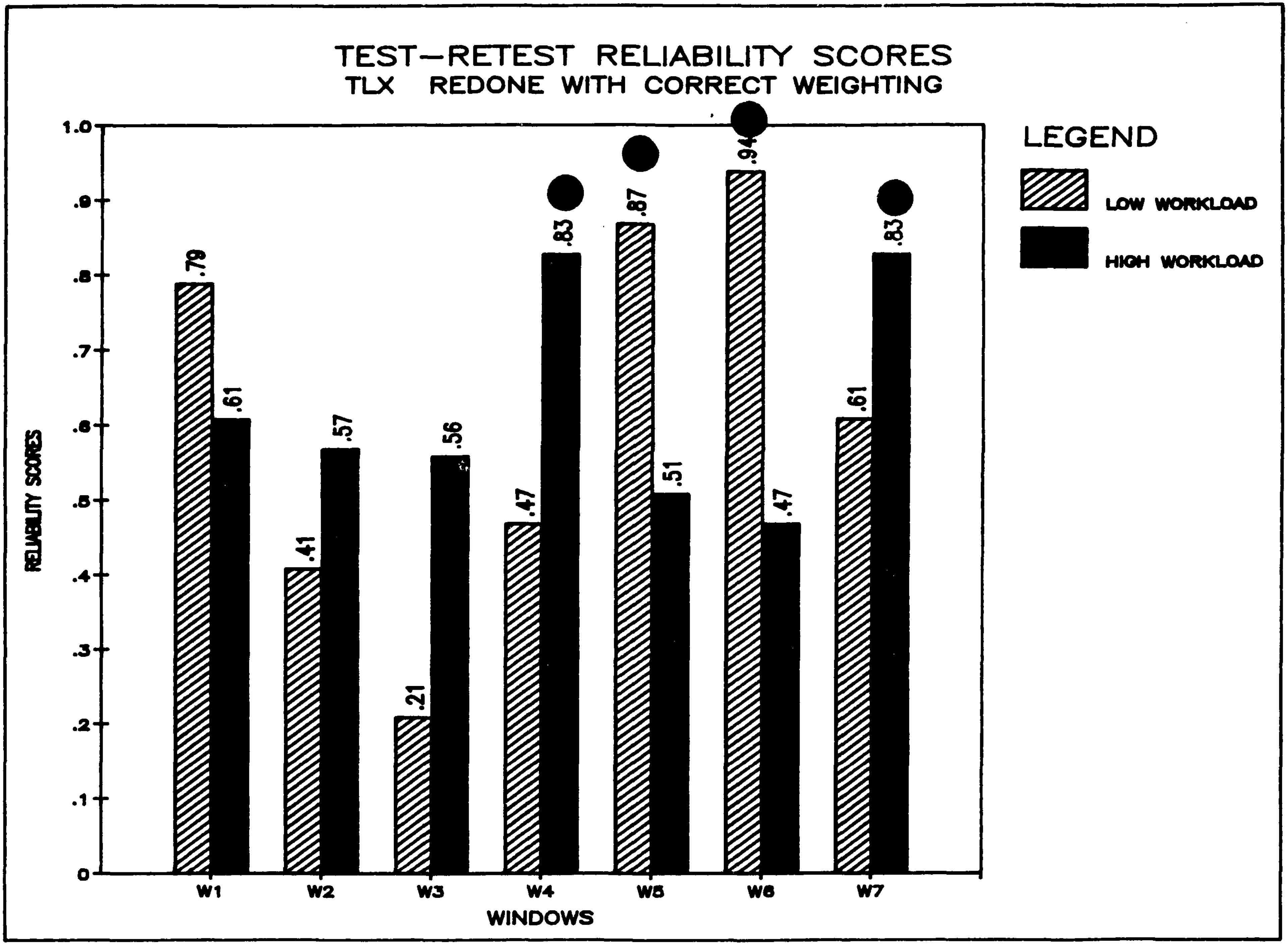

TEST—RETEST RELIABILITY SCORES
GROUP SOLUTIONS (SESSION ONE SORT)
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
RELIABILITY SCORES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
−.1
−.2
.46
.83
.44
.7
−.01
.8
.67
.46
−.18
.41
.1
.69
−.0005
.48
W1
W2
W3
W4
W5
W6
W7
WINDOWS

TASK LOAD INDEX (TLX)

- 6 BIPOLAR SCALES (MENTAL DEMAND, PHYSICAL DEMAND, TEMPORAL DEMAND, PERFORMANCE, EFFORT, FRUSTRATION)
- 20 POSSIBLE RATING VALUES FOR EACH BIPOLAR SCALE
- USES CONJOINT MEASUREMENT THEORY
- YIELDS SINGLE WORKLOAD SCORE WITH VALUE BETWEEN 0 – 100

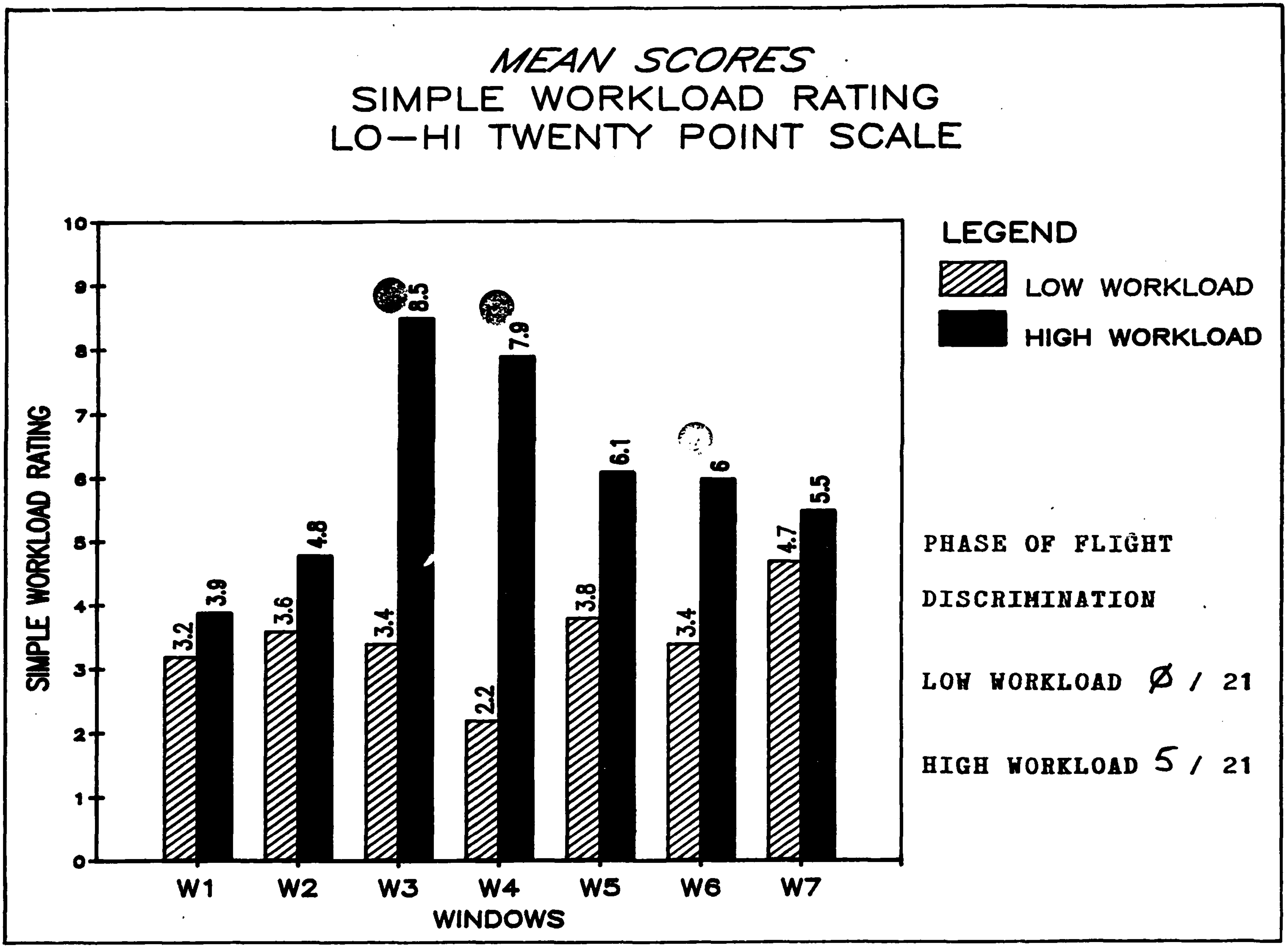


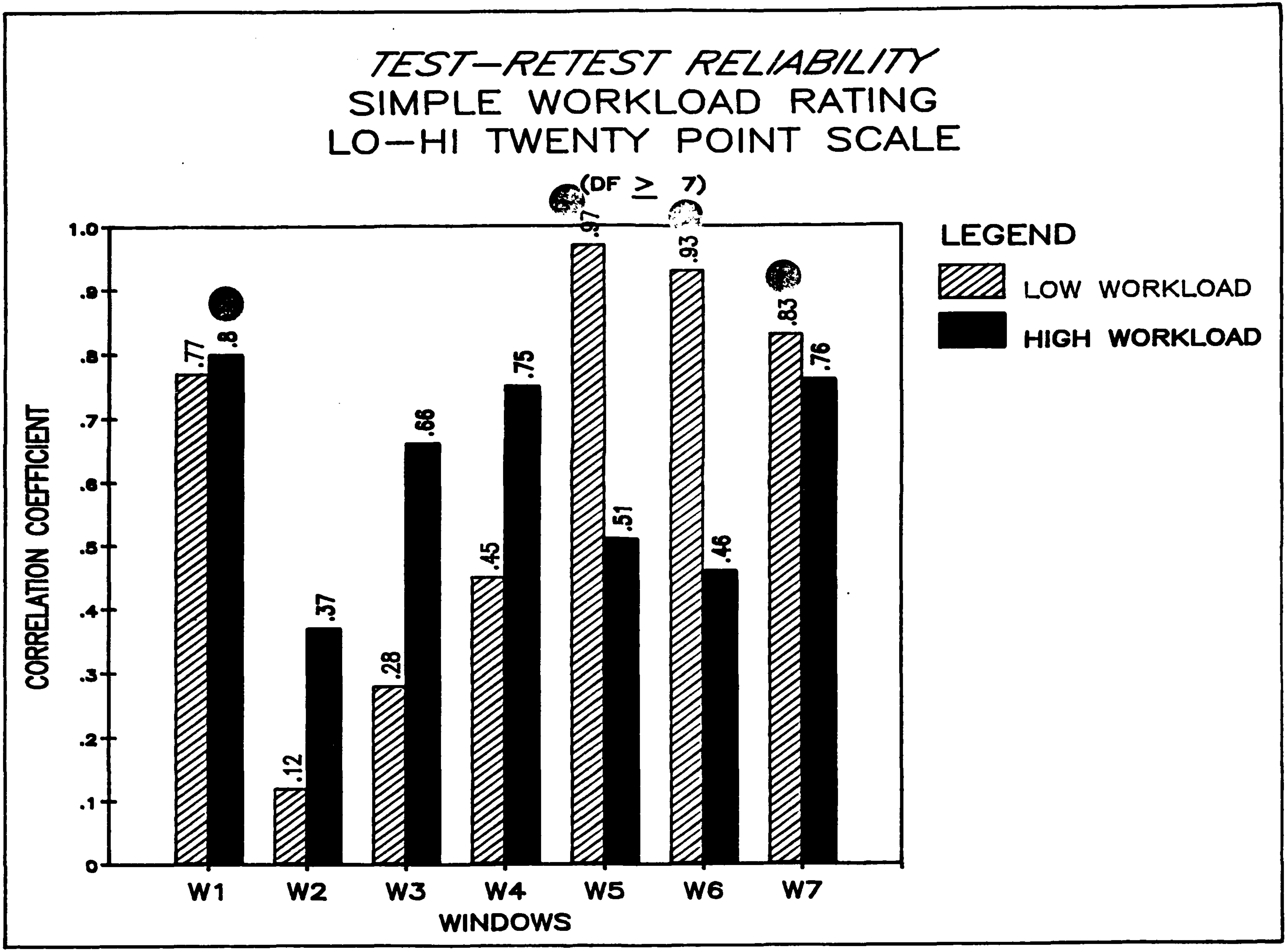
TLX WORKLOAD SCORES
(Redone with correct weights)
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
TLX SCORES
WINDOWS
W1
W2
W3
W4
W5
W6
W7
16.5
19.3
19.8
25.8
17.9
39.8
12.2
38.5
18.8
29.8
16.9
28.4
20.3
25.4
0
5
10
15
20
25
30
35
40
45
50


TEST—RETEST RELIABILITY SCORES
TLX REDONE WITH CORRECT WEIGHTING
RELIABILITY SCORES
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.79
.61
.41
.57
.21
.56
.47
.83
.87
.51
.94
.47
.61
.83
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD

OVERALL WORKLOAD SCORE

- ONE BIPOLAR SCALE (OVERALL WORKLOAD)
- 20 POSSIBLE RATING VALUES FOR SCALE


MEAN SCORES
SIMPLE WORKLOAD RATING
LO—HI TWENTY POINT SCALE
SIMPLE WORKLOAD RATING
10
9
8
7
6
5
4
3
2
1
0
3.2
3.9
3.6
4.8
3.4
8.5
2.2
7.9
3.8
6.1
3.4
6
4.7
5.5
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD Ø / 21
HIGH WORKLOAD 5 / 21



TEST-RETEST RELIABILITY
SIMPLE WORKLOAD RATING
LO-HI TWENTY POINT SCALE
(DF ≥ 7)
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
CORRELATION COEFFICIENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.77
.8
.12
.37
.28
.66
.45
.75
.97
.51
.93
.46
.83
.76
W1
W2
W3
W4
W5
W6
W7
WINDOWS

SUBJECTIVE MEASURES

SUMMARY

	SWAT(GROUP)	TLX	OWS
VALIDITY			
WORKLOAD DISCRIMINATION			
DIFFERENCES BETWEEN LOW AND HIGH WORKLOAD FLIGHTS?	YES	YES	YES
LOW-HIGH DIFFERENCES? (7 POSSIBLE)	2	3	3
PHASE OF FLIGHT DISCRIMINATION			
DIFFERENCES BETWEEN PHASE OF FLIGHT? (LOW)	NO	NO	NO
PHASE OF FLIGHT DIFFERENCES?	0	0	0
DIFFERENCES BETWEEN PHASE OF FLIGHT? (HIGH)	YES	YES	YES
PHASE OF FLIGHT DIFFERENCES?	3	4	5
RELIABILITY			
TEST-RETEST CORRELATIONS DAY 1 TO DAY 2 (14 POSSIBLE)	4	4	4
INTER-RATER AGREEMENT EACH PILOT CORRELATED TO GROUP AVERAGE	78%	78%	78%

PHYSIOLOGICAL MEASURES

Data was collected for horizontal and vertical eye movement (including blink), heart rate, and heart rate variability. Pilots were instrumented with Beckman mini-cup electrodes to record vertical and horizontal eye movement and had Electro-cardiogram electrodes applied to the chest to record heart rate.

Although the data demonstrates good reliability for both TEST-RETEST and INTER-RATER, eyeblinks per minute cannot discriminate low and high workload conditions.

Inter-beat intervals (IBI's), which tell how much time occurs between heart beats, rather than heart rate, which refers to how many beats occur in a minute, was used in the data analysis. The MEAN and STANDARD DEVIATION of the IBI values for each window were computed. The MEAN IBI measure was sensitive to the differences between low and high workload conditions. In addition it could discriminate phases of flight (between the measurement windows in a given workload condition) better than any other workload measure in the present study. The reliability measures, both TEST-RETEST and INTER-RATER, were consistently high for the mean IBI measure of workload. IBI VARIABILITY was not able to discriminate the difference between low and high workload conditions, although a strong trend exists. TEST-RETEST reliability for IBI VARIABILITY was not as high as IBI MEAN, nor was INTER-RATER reliability as high as the IBI MEAN data.

A heart rate spectral analysis was also conducted using software provided by Randall Harris and Allen Pope of NASA-Langley. The Blood Pressure Component, predicted to decrease when the pilot is engaged in a cognitive task, was not able to discriminate the difference between low and high workload. It was also poor in reliability and it had the worst performance on TEST-RETEST and INTER-RATER reliability measures of all the physiological workload measures. The Respiration Component was able to discriminate the low and high workload conditions. Similar to the other heart spectral analysis measure, the Respiration Component did not demonstrate high reliability in either the TEST-RETEST or INTER-RATER reliability measures.

On the transparencies dots are used to denote a statistically significant relationship.

- o On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.

- o On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

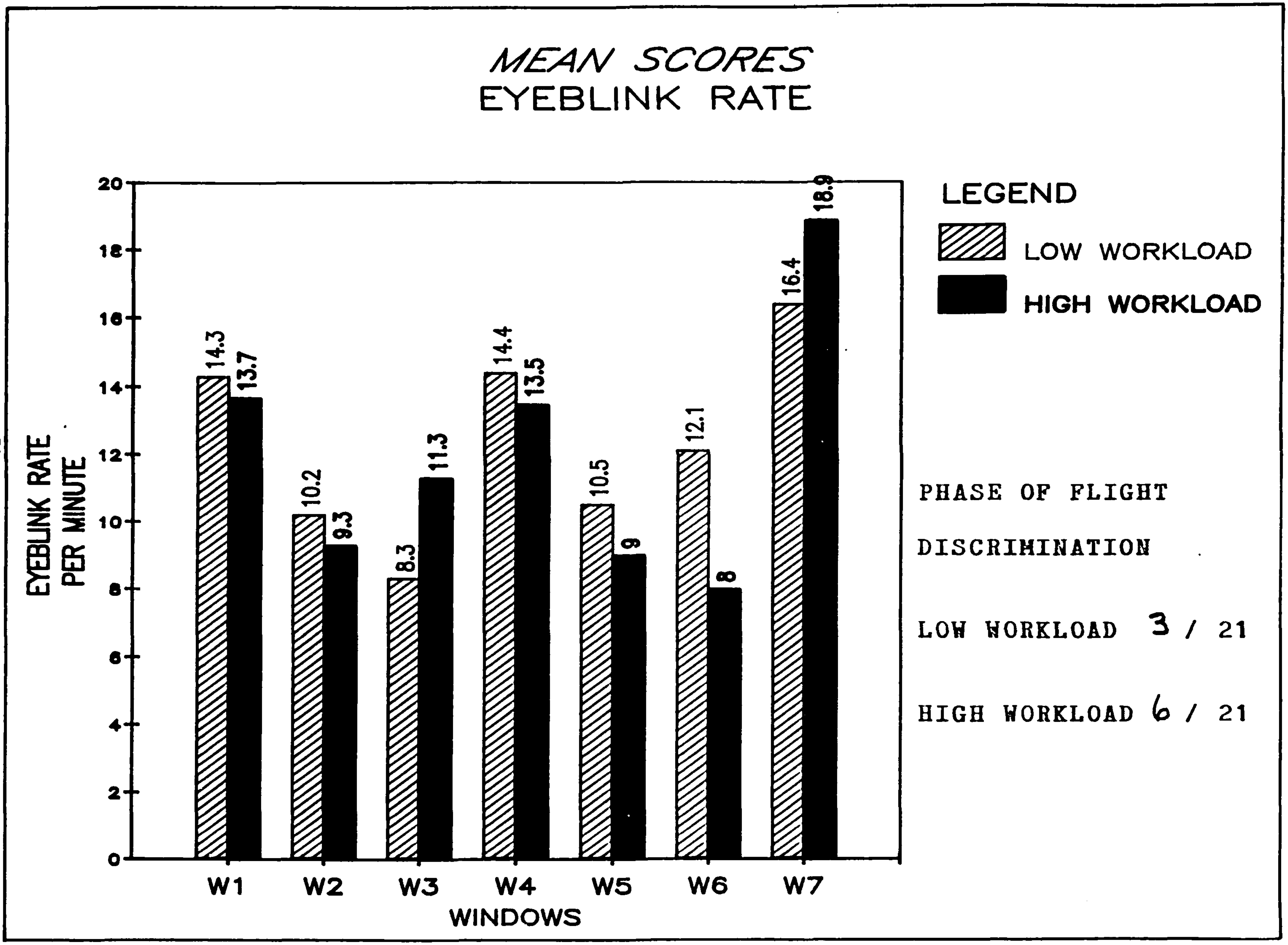
Following are the transparencies presented on the analysis of the physiological data.

PHYSIOLOGICAL MEASURES

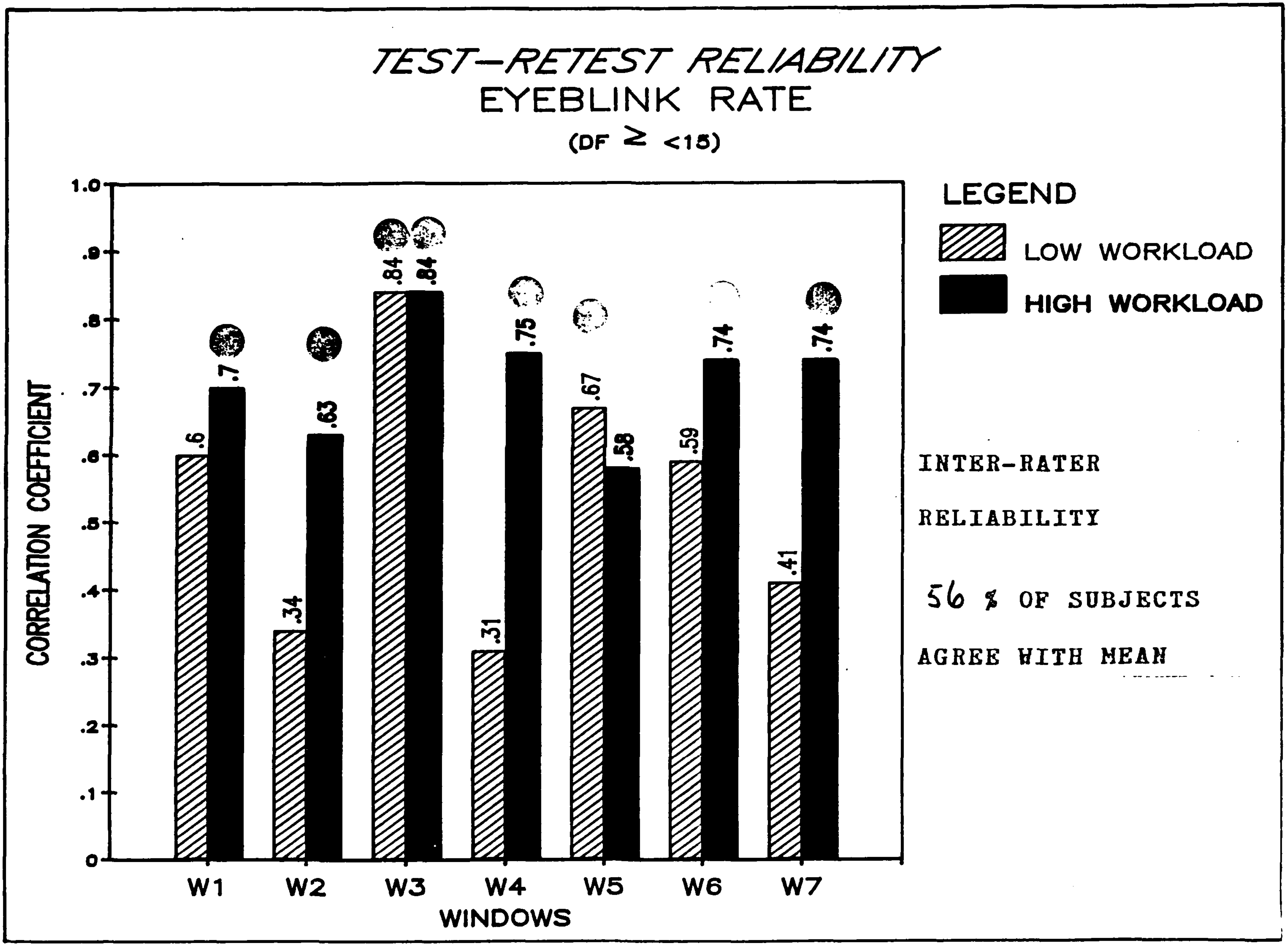
- EYEBLINK RATE
- HEART
  - RATE
  - RATE VARIABILITY
- HEART SPECTRAL ANALYSIS
  - BLOOD PRESSURE COMPONENT
  - RESPIRATION COMPONENT

EYEBLINK RATE

- BLINKS PER MINUTE = BLINK COUNT/WINDOW TIME
- INCREASES WITH GAZE SHIFTS
  - ATTENDING TO MULTIPLE VISUAL TARGETS
- DECREASES WITH INCREASED CONCENTRATION
  - ATTENDING TO A SINGLE VISUAL TARGET



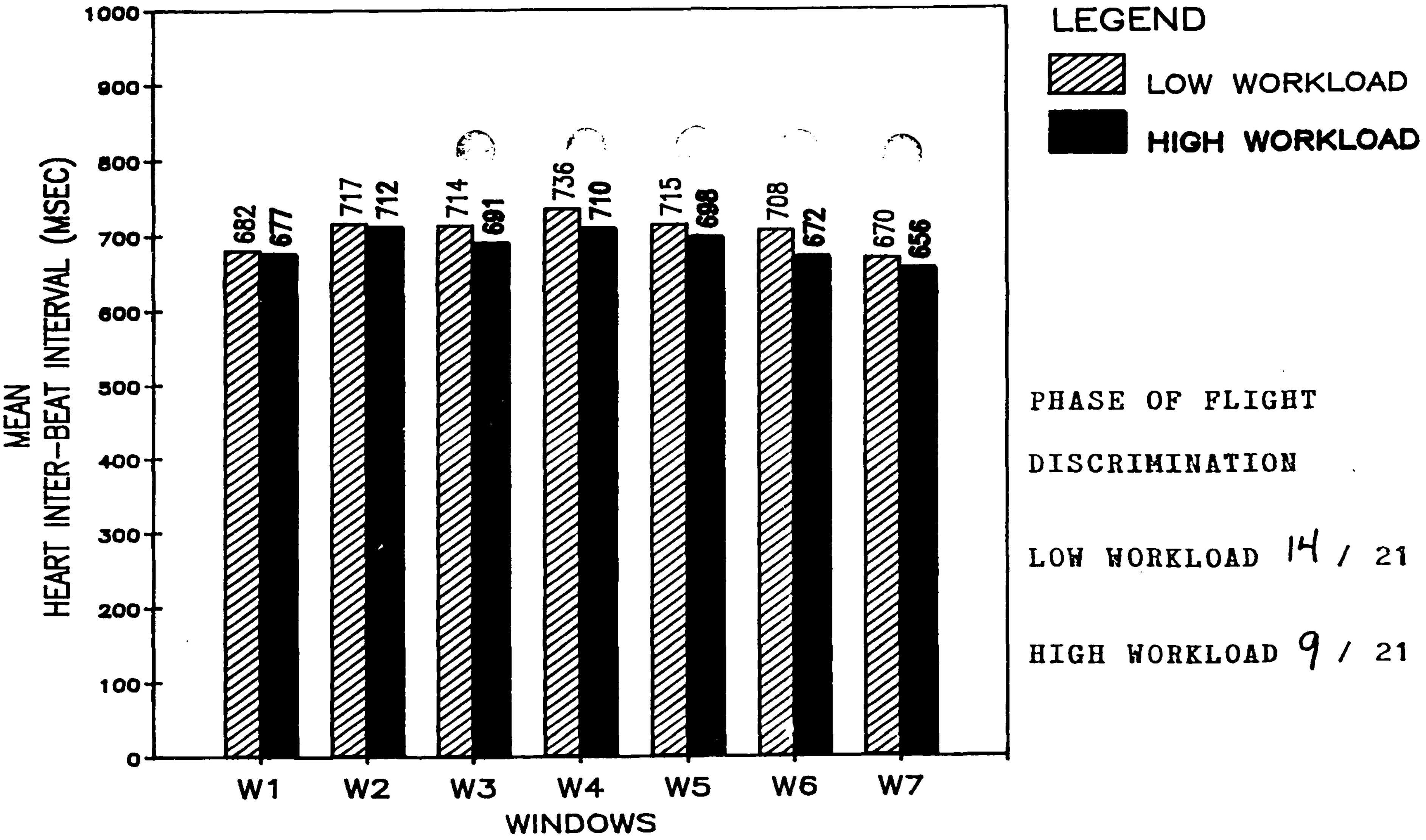
MEAN SCORES
EYEBLINK RATE
EYEBLINK RATE PER MINUTE
0
2
4
6
8
10
12
14
16
18
20
14.3
13.7
10.2
9.3
8.3
11.3
14.4
13.5
10.5
9
12.1
8
16.4
18.9
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD 3 / 21
HIGH WORKLOAD 6 / 21


TEST—RETEST RELIABILITY
EYEBLINK RATE
(DF ≥ <15)
CORRELATION COEFFICIENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.6
.7
.34
.63
.84
.84
.31
.75
.67
.58
.59
.74
.41
.74
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
56 % OF SUBJECTS
AGREE WITH MEAN

HEART RATE (AVERAGED INTER—BEAT INTERVALS)

- HEART RATE (BEATS PER MIN.) = (1/IBI TIME) X 60
- VARIES AS A DIRECT FUNCTION OF METABOLIC DEMANDS
- INCREASES WITH INCREASING TASK DEMANDS

MEAN SCORES
HEART BEAT (IBI UNITS): RATE

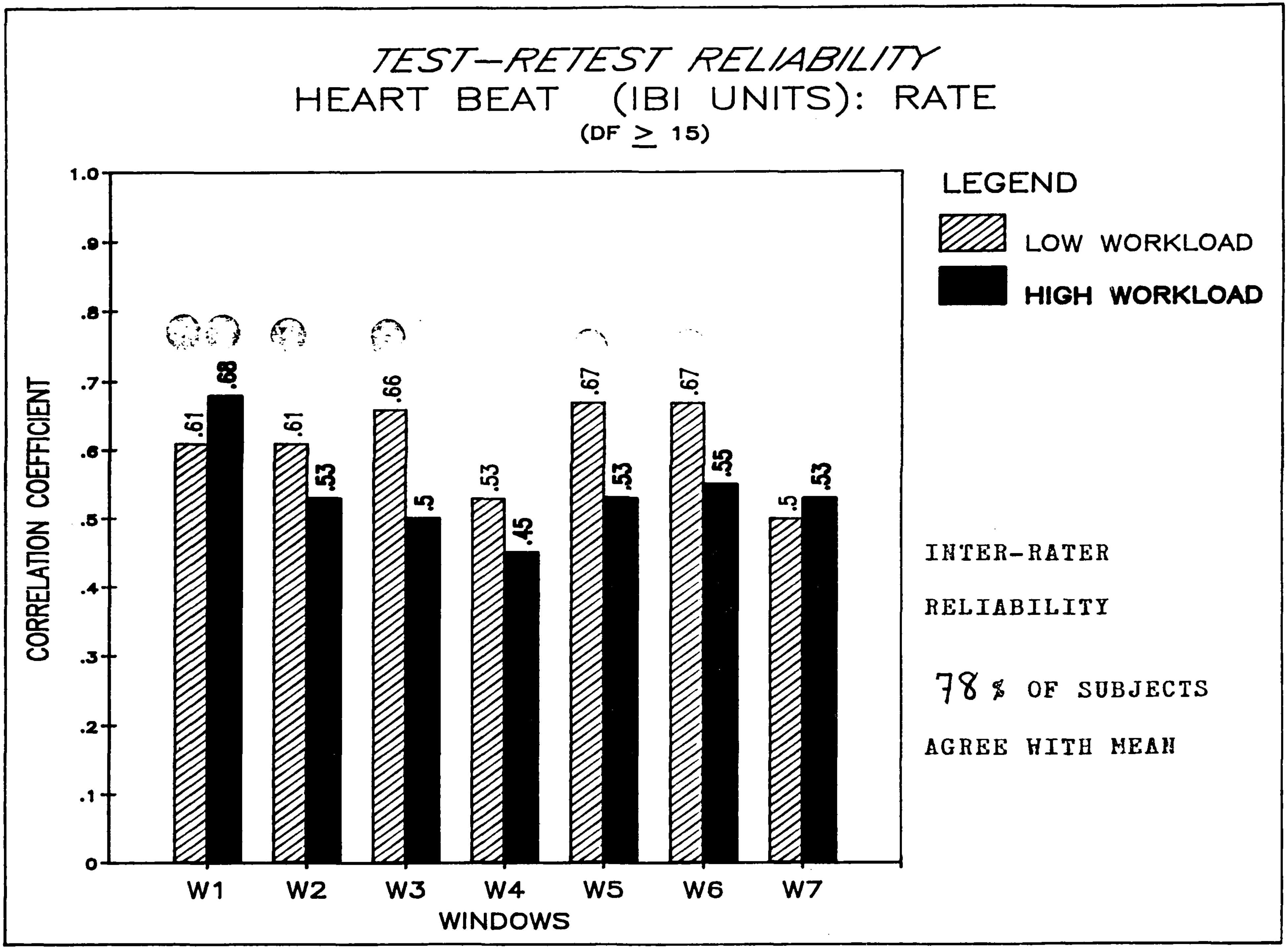


PHASE OF FLIGHT

DISCRIMINATION

LOW WORKLOAD 14 / 21

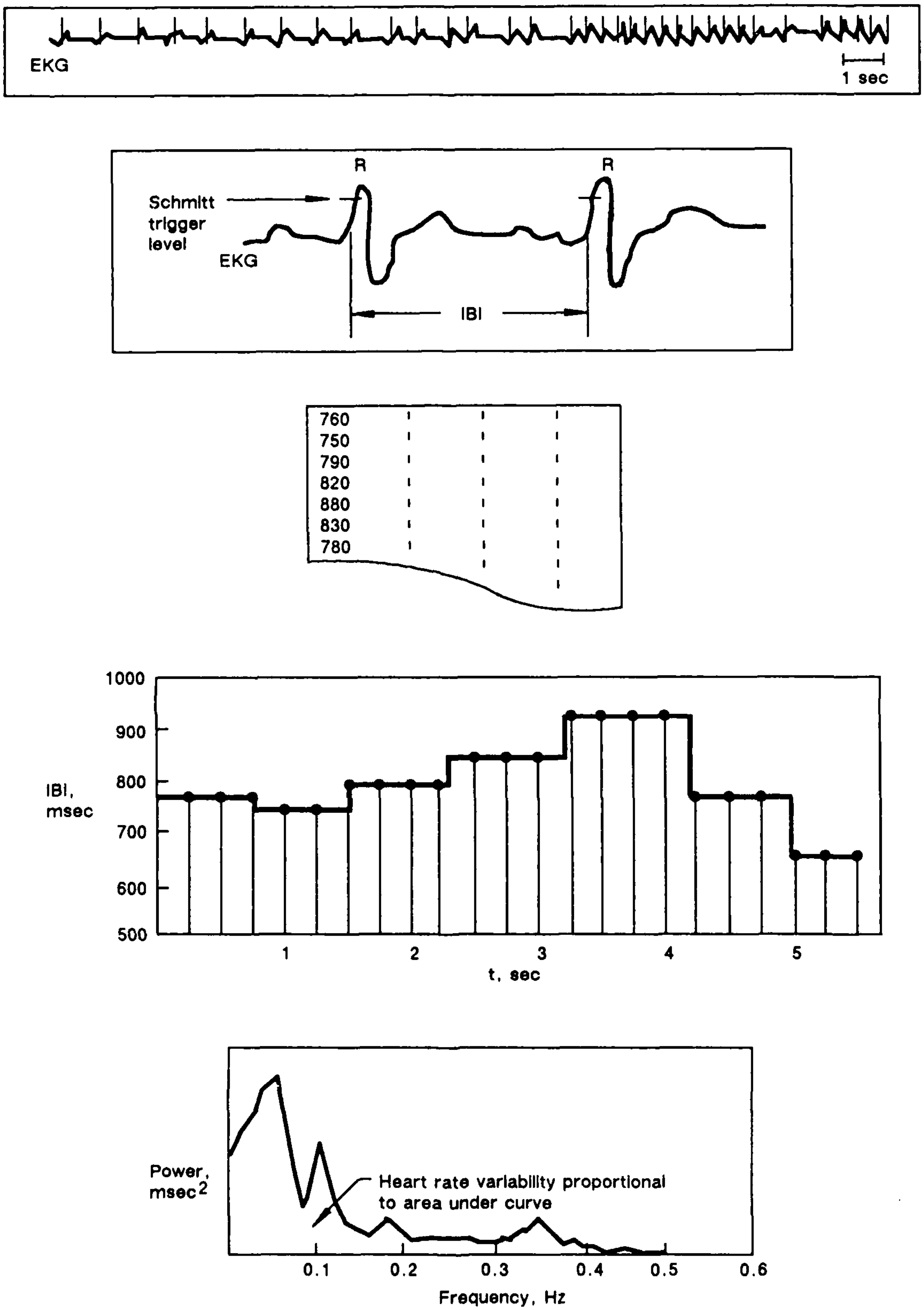
HIGH WORKLOAD 9 / 21



TEST–RETEST RELIABILITY
HEART BEAT (IBI UNITS): RATE
(DF ≥ 15)
CORRELATION COEFFICIENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.61
.68
.61
.53
.66
.5
.53
.45
.67
.53
.67
.55
.5
.53
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
78 % OF SUBJECTS
AGREE WITH MEAN

HEART RATE VARIABILITY

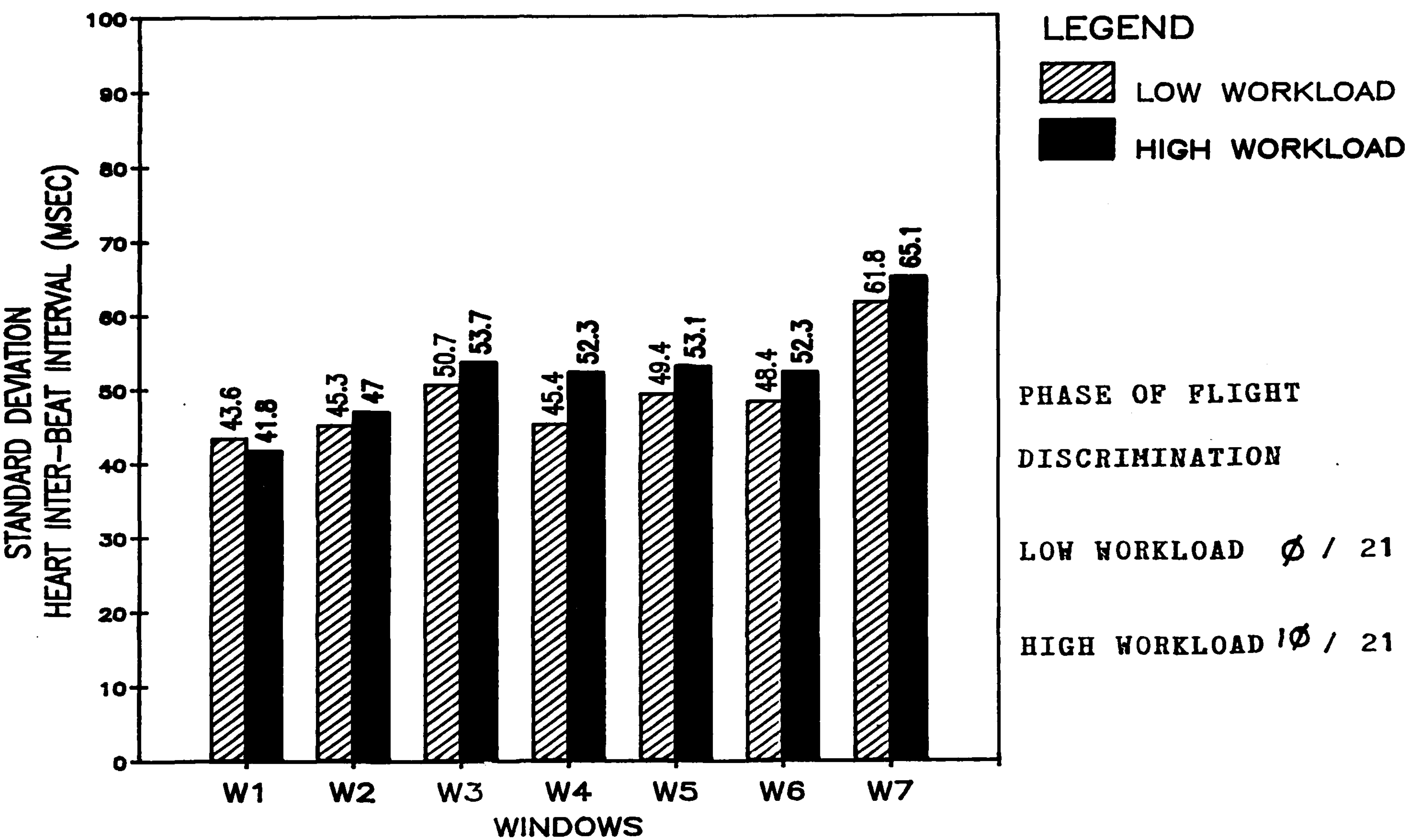
- HEART RATE VARIABILITY = STANDARD DEVIATION OF IBI DATA
- REFLECTS THE SUM OF ALL SOURCES EFFECTING CHANGES IN HEART RATE



4-U80069pk1-2

MEAN SCORES

HEART BEAT (IBI UNITS): VARIABILITY



PHASE OF FLIGHT

DISCRIMINATION

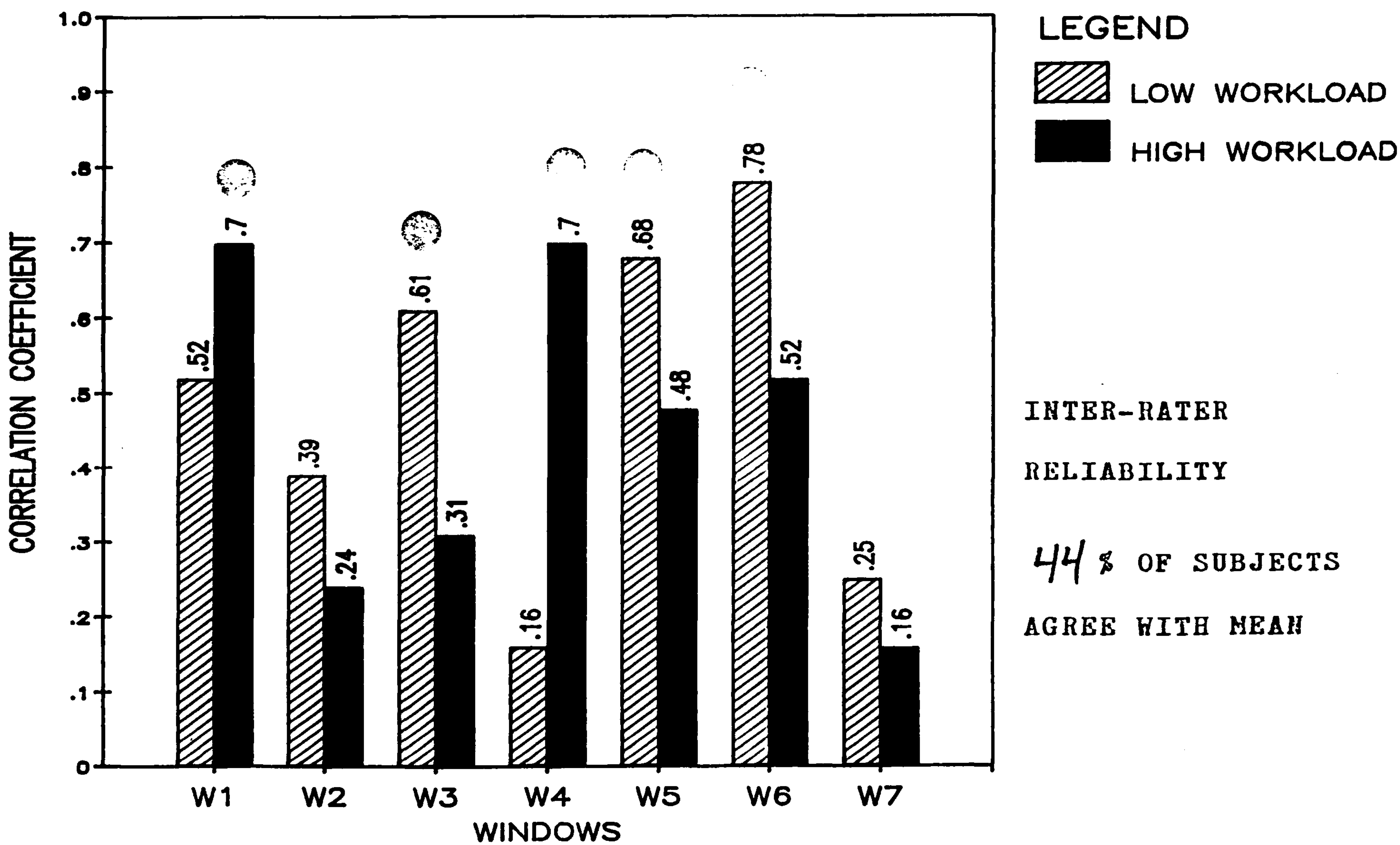
LOW WORKLOAD Ø / 21

HIGH WORKLOAD 1Ø / 21

TEST—RETEST RELIABILITY

HEART BEAT (IBI UNITS): VARIABILITY

(DF $\geq$ 15)



INTER-RATER

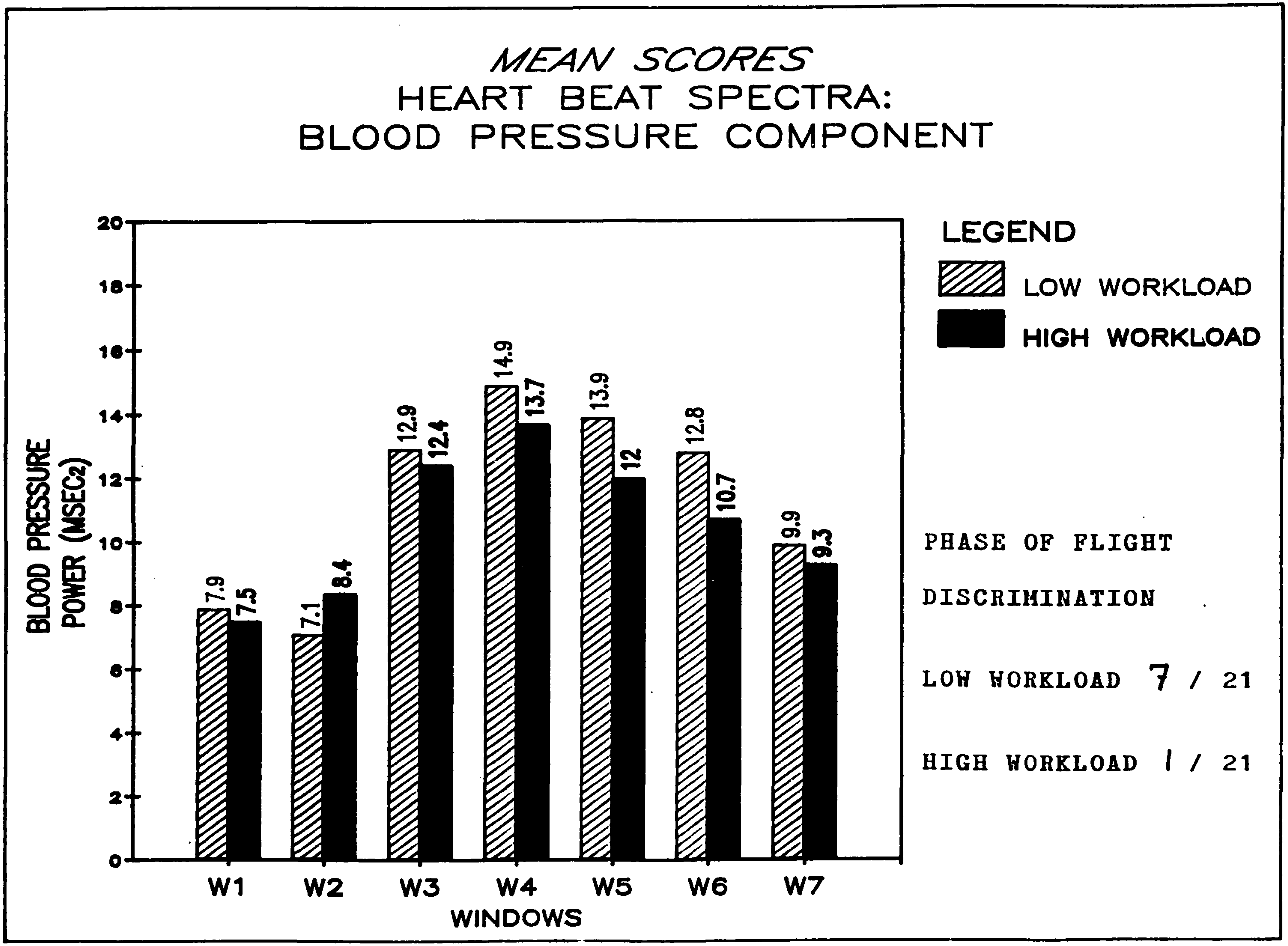
RELIABILITY

44 % OF SUBJECTS

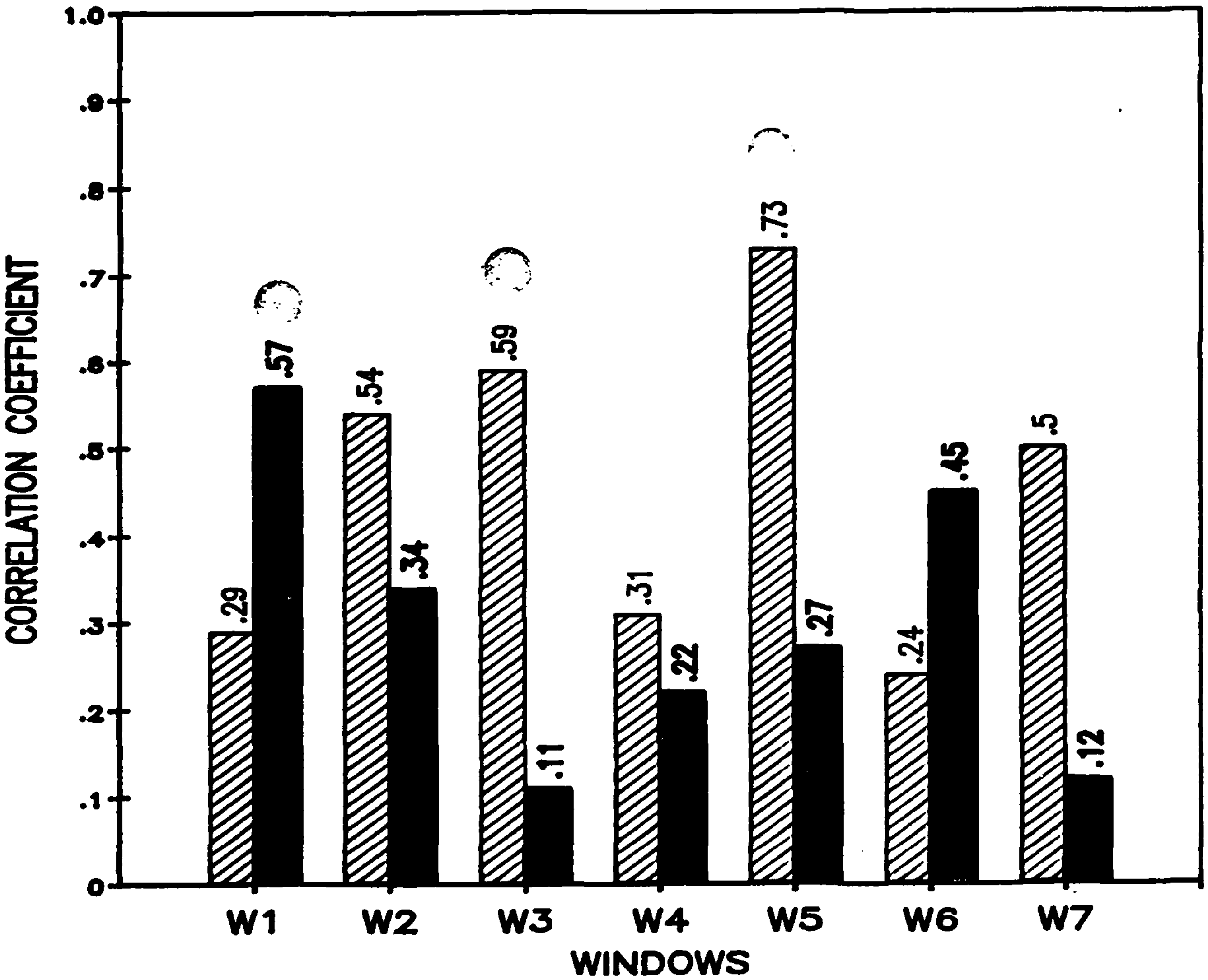
AGREE WITH MEAN

HEART SPECTRAL ANALYSIS

- FOURIER TRANSFORM OF IBI DATA
  - YIELDS POWER WITHIN FREQUENCY BANDS
- BLOOD PRESSURE COMPONENT
  - .05 TO .15 hertz
  - DECREASES WHEN ENGAGED IN COGNITIVE TASKS
- RESPIRATION COMPONENT
  - .20 TO .40 hertz
  - INCREASES WITH CHANGES IN METABOLIC DEMANDS


MEAN SCORES
HEART BEAT SPECTRA:
BLOOD PRESSURE COMPONENT
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
BLOOD PRESSURE POWER (MSEC2)
0
2
4
6
8
10
12
14
16
18
20
7.9
7.5
7.1
8.4
12.9
12.4
14.9
13.7
13.9
12
12.8
10.7
9.9
9.3
W1
W2
W3
W4
W5
W6
W7
WINDOWS
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD 7 / 21
HIGH WORKLOAD 1 / 21

TEST-RETEST RELIABILITY
HEART BEAT SPECTRA: BLOOD PRESSURE COMPONENT
(DF ≥ 15)



LEGEND

LOW WORKLOAD

HIGH WORKLOAD

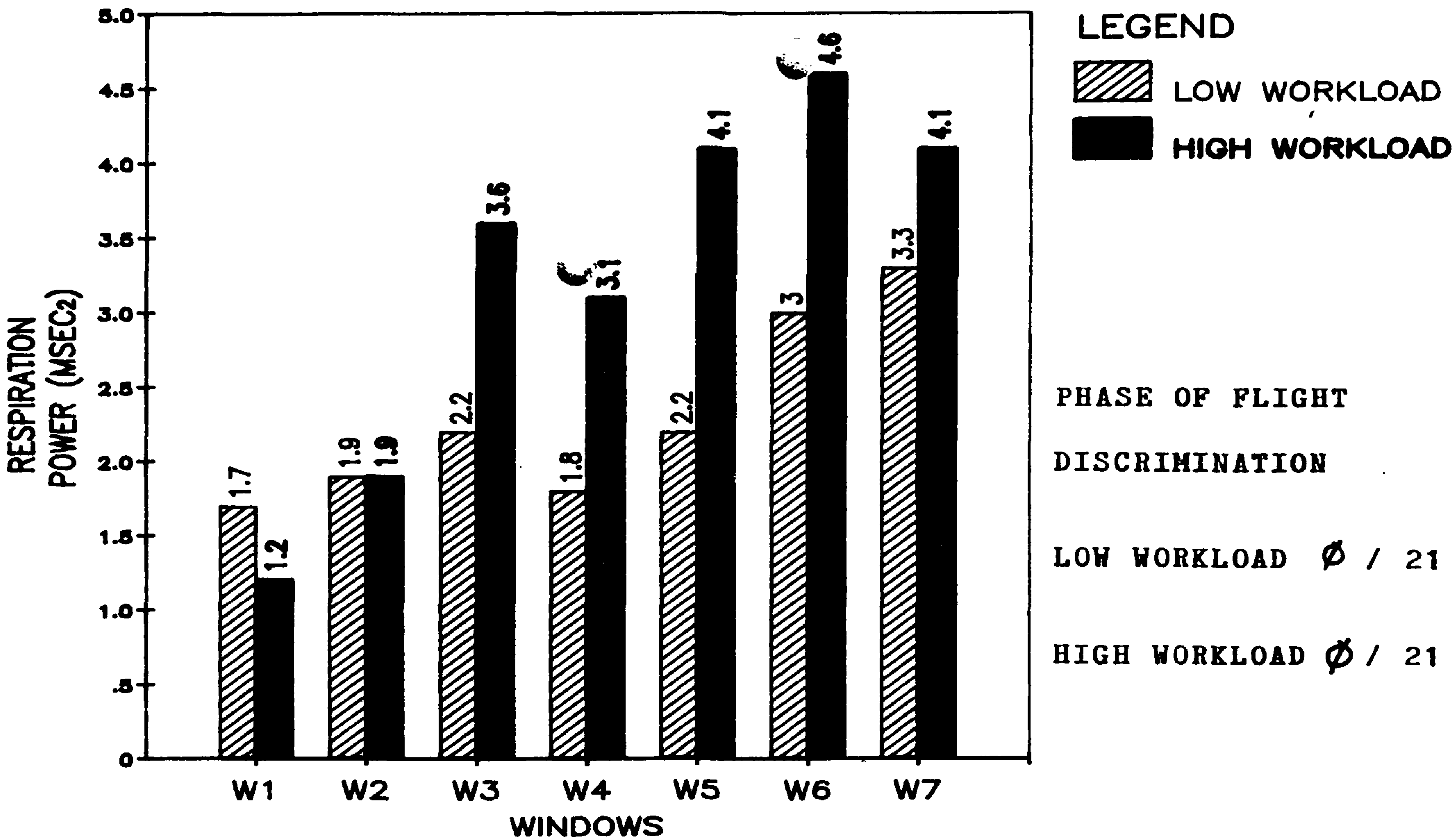
INTER-RATER

RELIABILITY

17 % OF SUBJECTS

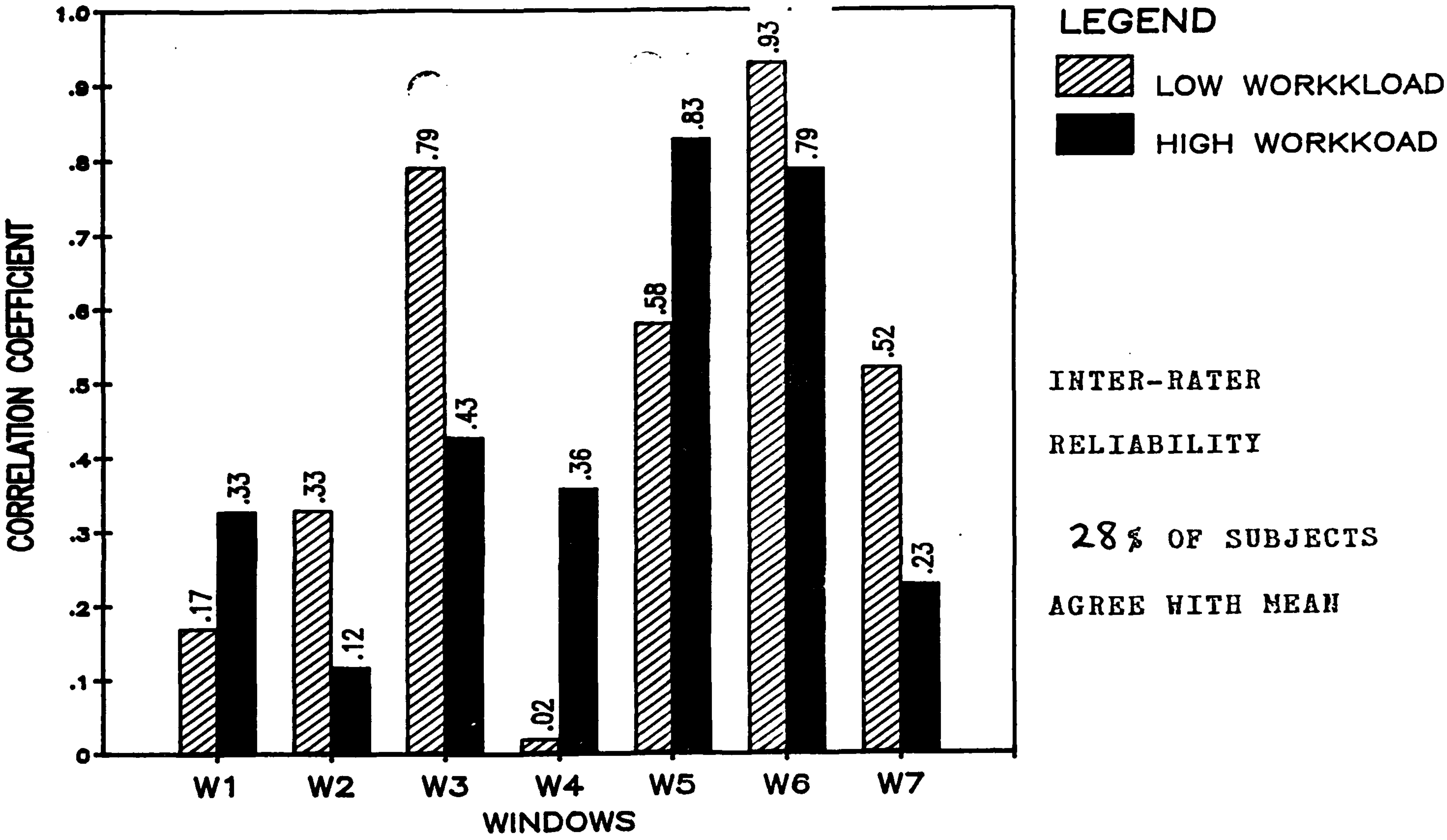
AGREE WITH MEAN

MEAN SCORES
HEART BEAT SPECTRA: RESPIRATION COMPONENT



TEST–RETEST RELIABILITY
HEART BEAT SPECTRA: RESPIRATION COMPONENT

(DF ≥ 15)



INTER-RATER

RELIABILITY

28% OF SUBJECTS

AGREE WITH MEAN

PHYSIOLOGICAL MEASURES

SUMMARY

VALIDITY	EB	HBR	HBV	HSB	HSR
WORKLOAD DISCRIMINATION					
DIFFERENCES BETWEEN LOW AND HIGH WORKLOAD FLIGHT?	NO	YES	NO	NO	YES
LOW-HIGH DIFFERENCES? (7 POSSIBLE)	0	5	0	0	2
PHASE-OF-FLIGHT DISCRIMINATION					
DIFFERENCES BETWEEN PHASE-OF-FLIGHT? **(LOW)**	YES	YES	YES	YES	YES
PHASE-OF-FLIGHT DIFFERENCES? (21 POSSIBLE)	3	14	0	7	0
DIFFERENCES BETWEEN PHASE-OF-FLIGHT? **(HIGH)**	YES	YES	YES	YES	YES
PHASE-OF-FLIGHT DIFFERENCES? (21 POSSIBLE)	6	9	10	1	0
RELIABILITY					
TEST-RETEST CORRELATIONS: DAY 1 TO DAY 2 (14 POSSIBLE)	7	6	5	3	5
INTER-RATER AGREEMENT: EACH PILOT TO GROUP AVERAGE	56%	78%	44%	17%	28%

EB -- Eye Blinks

HBR -- Heart Beat Rate

HBV -- Heart Beat Variability

HSB -- Heart Spectra - Blood Pressure Component

HSR -- Heart Spectra - Respiration Component

PERFORMANCE DATA

Data from the simulator was collected during the measurement windows. Position information of the flight controls (wheel, column and pedals) were transformed into a measure of control activity labelled Control Input. In addition altitude over the outer and middle markers, flight director deviation, glideslope and localizer deviation, and lateral deviation from runway centerline was collected in the Approach and Landing windows. Since the measurement windows cover different lengths of time, the control activity is divided by units of time to yield the Control Input measure. This measure indicates the amount of significant control activity per minute. There was a strong indication that Control Input could discriminate between the two levels of workload.

If the pilot placed the plane on autopilot, the data for control position and consequently Control Input, was not collected. As a result there are measurement windows in the low workload condition which do not contain much data, making the comparison of low and high workload conditions meaningless from a statistical point of view. Even with the missing data, however, there is still a strong indication the Control Input can discriminate low and high workload conditions.

On the transparencies dots are used to denote a statistically significant relationship.

- o On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.

- o On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

Following are the transparencies presented on the analysis of the performance data.

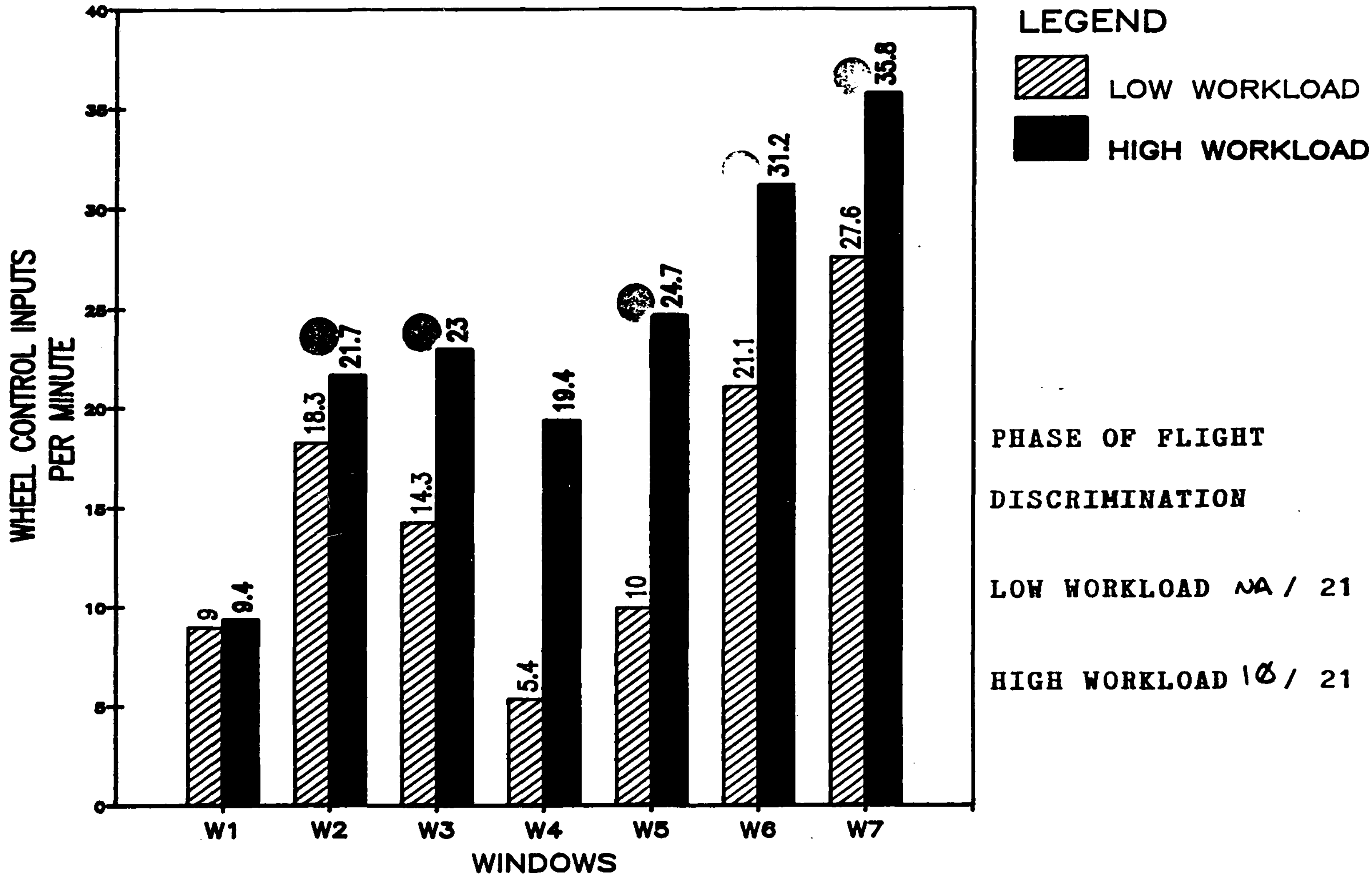
PERFORMANCE MEASURES

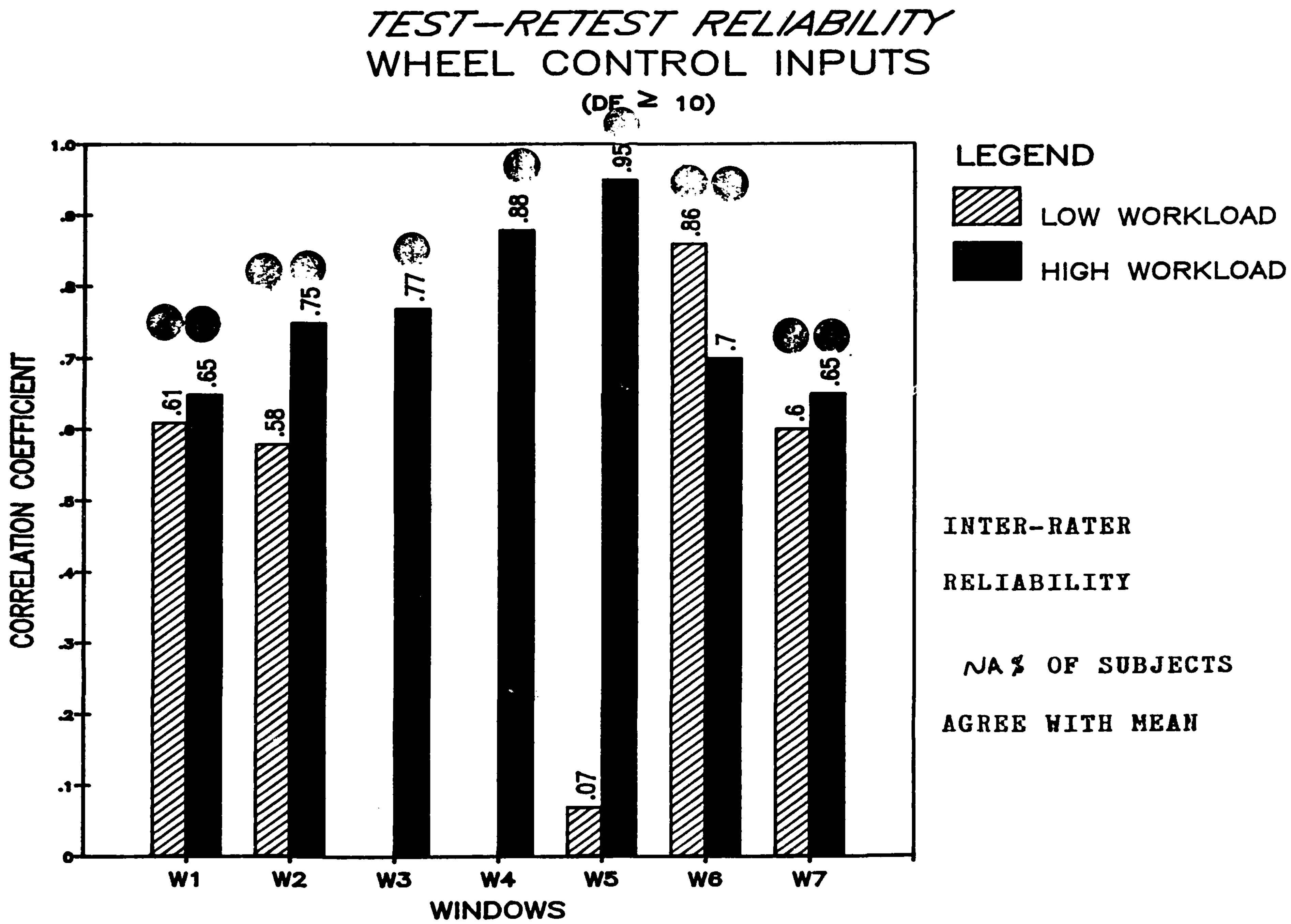
- WHEEL CONTROL INPUTS
- STICK CONTROL INPUTS
- PEDAL CONTROL INPUTS
- SECONDARY TASK RESPONSE TIMES
- SECONDARY TASK PROBE RECOGNITION ACCURACY

WHEEL CONTROL INPUT

- WHEEL POSITION INFORMATION COLLECTED AT 10 hertz RATE
- 2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER
- VALUES PRESENTED PER UNIT TIME (WHEEL CONTROL INPUTS / MINUTE)

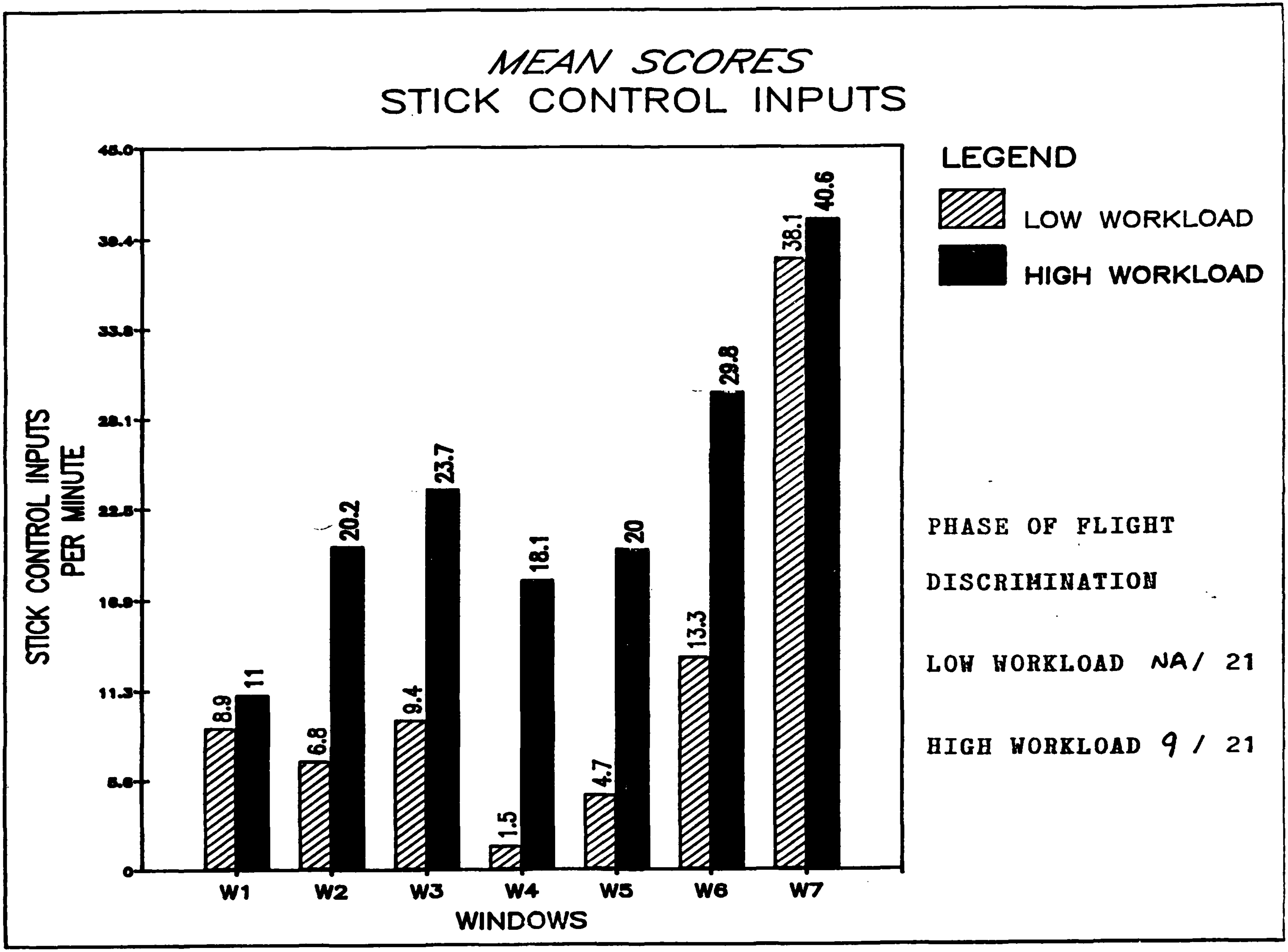
MEAN SCORES
WHEEL CONTROL INPUTS

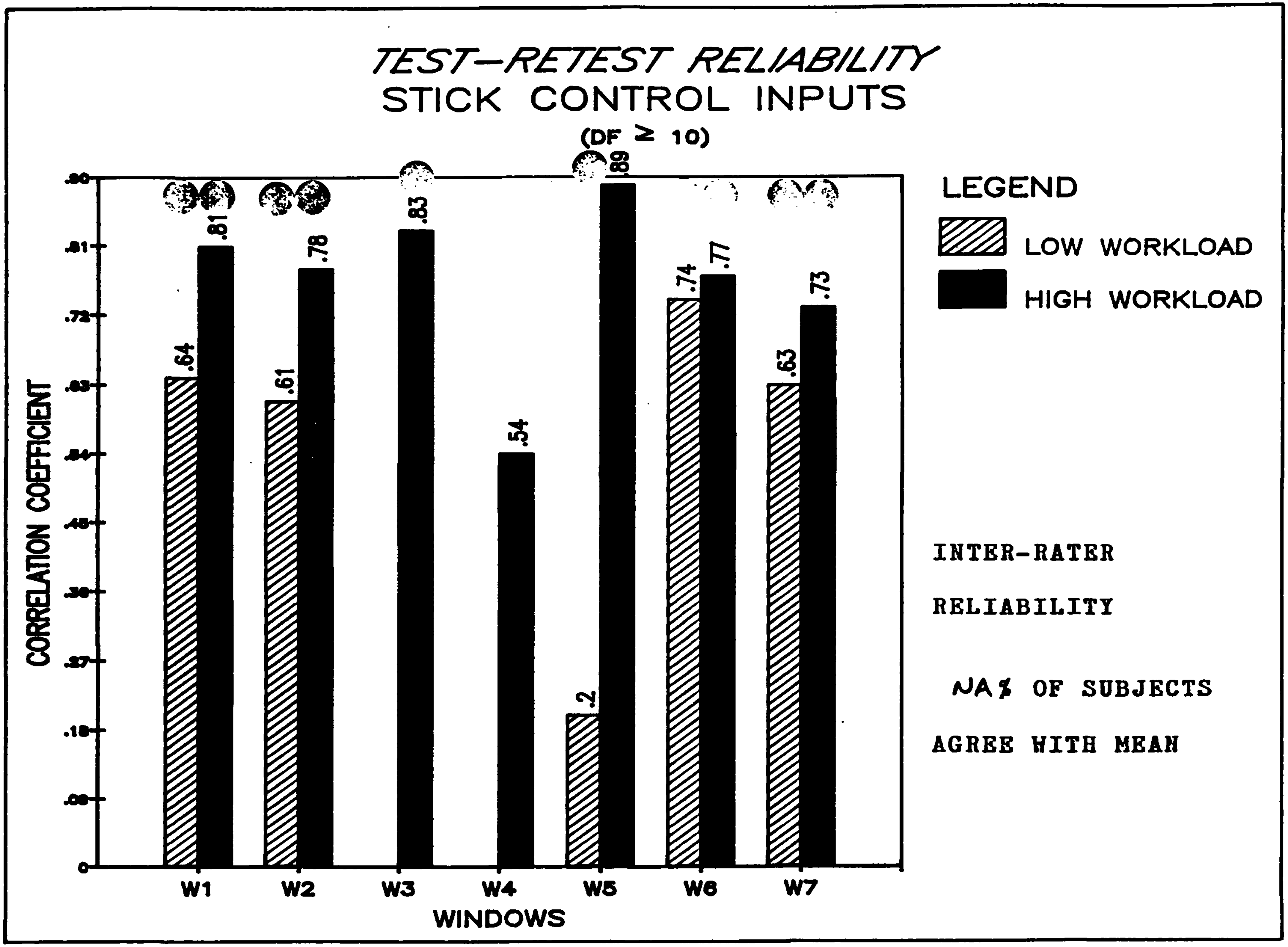



TEST-RETEST RELIABILITY
WHEEL CONTROL INPUTS
(DF ≥ 10)
CORRELATION COEFFICIENT
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
.61
.65
.58
.75
.77
.88
.07
.95
.86
.7
.6
.65
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
NA % OF SUBJECTS
AGREE WITH MEAN

STICK CONTROL INPUT

- STICK POSITION INFORMATION COLLECTED AT 10 hertz RATE
- 2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER
- VALUES PRESENTED PER UNIT TIME (STICK CONTROL INPUTS / MINUTE)


MEAN SCORES
STICK CONTROL INPUTS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
STICK CONTROL INPUTS PER MINUTE
45.0
39.4
33.8
28.1
22.5
16.9
11.3
5.6
0
8.9
11
6.8
20.2
9.4
23.7
1.5
18.1
4.7
20
13.3
29.8
38.1
40.6
W1
W2
W3
W4
W5
W6
W7
WINDOWS
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD NA/ 21
HIGH WORKLOAD 9 / 21

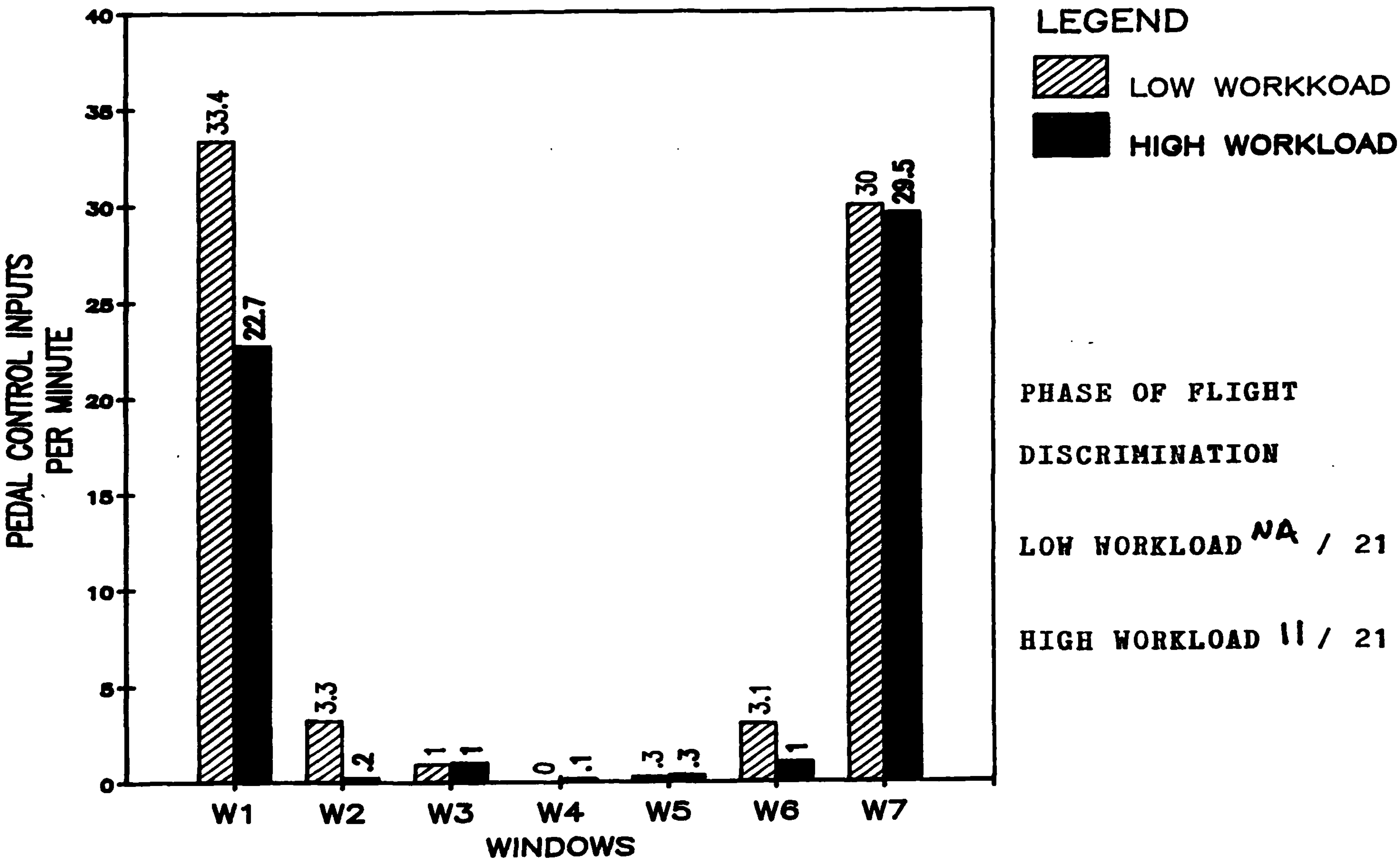


TEST-RETEST RELIABILITY
STICK CONTROL INPUTS
(DF ≥ 10)
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
NA% OF SUBJECTS
AGREE WITH MEAN
CORRELATION COEFFICIENT
.90
.81
.72
.63
.54
.45
.36
.27
.18
.09
0
.64
.81
.61
.78
.83
.54
.2
.89
.74
.77
.63
.73
W1
W2
W3
W4
W5
W6
W7
WINDOWS

PEDAL CONTROL INPUT

- PEDAL POSITION INFORMATION COLLECTED AT 10 hertz RATE
- 2.5% CHANGE FROM ONE DATA POINT TO THE NEXT INCREMENTS COUNTER
- VALUES PRESENTED PER UNIT TIME (PEDAL CONTROL INPUTS / MINUTE)

MEAN SCORES
PEDAL CONTROL INPUTS

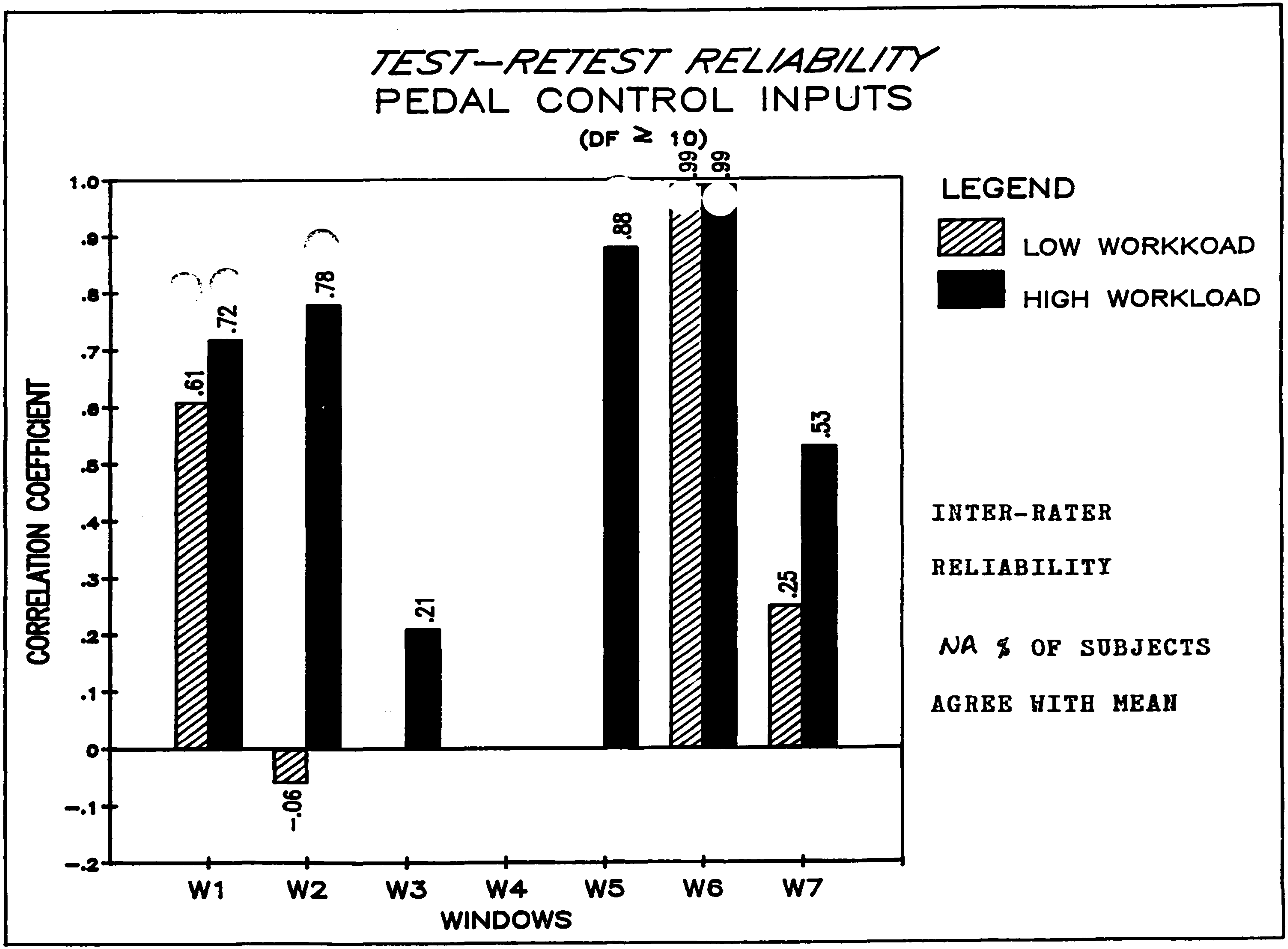


PHASE OF FLIGHT

DISCRIMINATION

LOW WORKLOAD NA / 21

HIGH WORKLOAD 11 / 21


TEST—RETEST RELIABILITY
PEDAL CONTROL INPUTS
(DF ≥ 10)
LEGEND
LOW WORKKOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
NA % OF SUBJECTS
AGREE WITH MEAN
CORRELATION COEFFICIENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
.61
.72
-.06
.78
.21
.88
.99
.99
.25
.53
W1
W2
W3
W4
W5
W6
W7
WINDOWS

SECONDARY TASK MEASURES

A secondary task was implemented to measure pilot's spare capacity (spare capacity is thought to be correlated with workload). The secondary task was a response time task. ATC would start a timer when they issued calls to aircraft designated as positive probes. The positive probe aircraft were the pilot's own aircraft or another aircraft in the area. All other aircraft were designated negative probes. The pilots pressed the push to talk switch on the left side of the yoke when they heard the call sign of the aircraft designated as positive probes and this stopped the timer ATC had activated. Two measures can be derived from the Secondary Task, response time and probe accuracy.

A post hoc examination of the accuracy of probe delivery indicates that ATC personnel did not deliver the probes in a consistent fashion across the different subjects. Also, responses which took longer than 10 seconds were disregarded because the task was not executed immediately. Even with all the flaws in the data collection there was a clear trend for a discrimination between the low and high workload conditions for Secondary Task Response Time. No clear trends for discriminating low and high workload are found for Probe Accuracy. A statistical analysis of the reliability measures is not possible for either Response Time or Probe Accuracy because of the discrepant sample sizes due to the flawed probe presentation.

On the transparencies dots are used to denote a statistically significant relationship.

- o On the chart including "means" for the workload measure the dot represents a significant difference between low and high workload for a given measurement window.

- o On the chart including "correlation coefficients" for the workload measure the dot represents a significant correlation comparing test to retest for a given measurement window

Following are the transparencies presented on the analysis of the secondary task measure data.

SECONDARY TASK

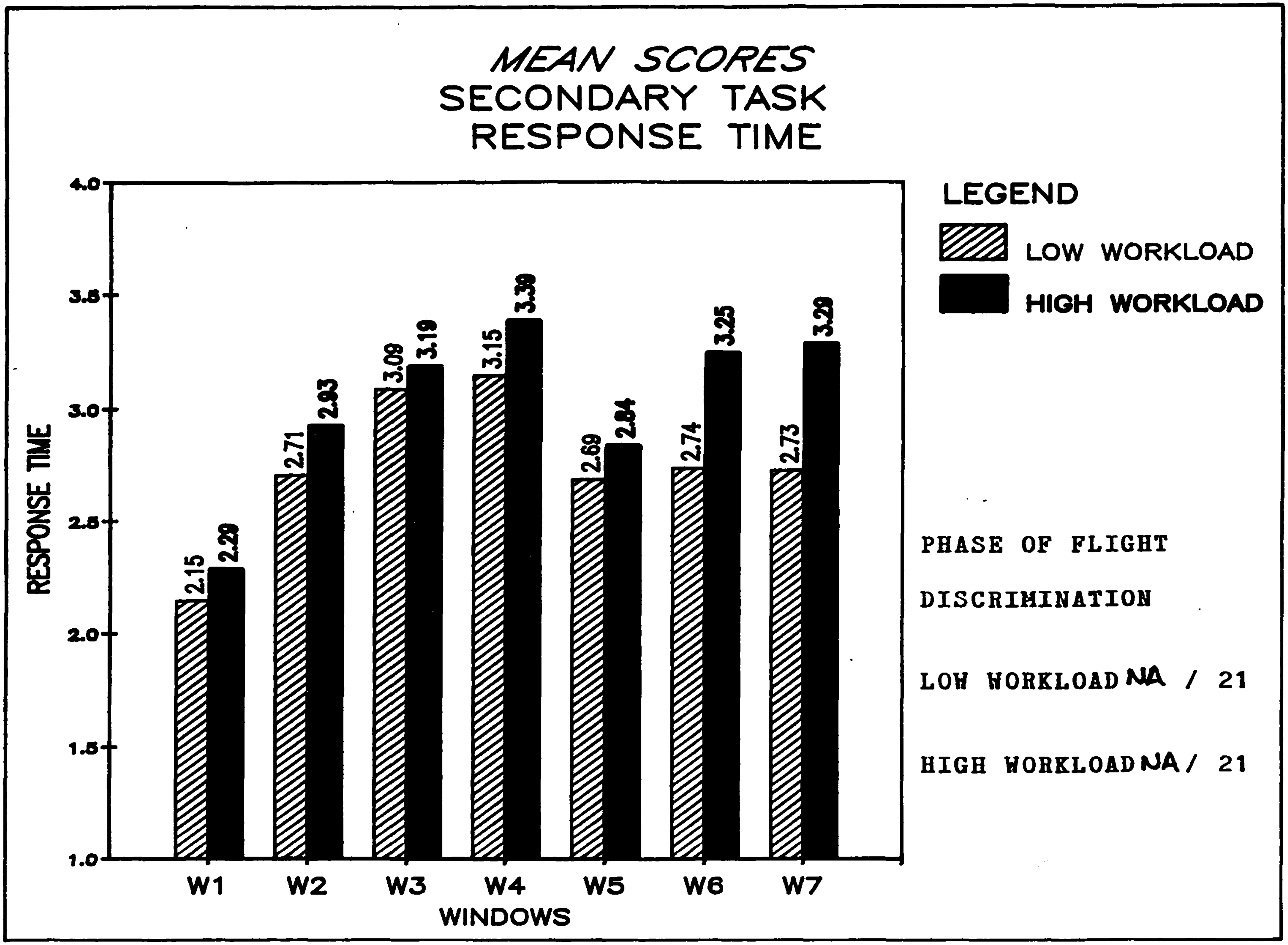
- TWO 'FLIGHT NUMBERS' ARE DESIGNATED POSITIVE PROBES
  - PILOT'S OWN FLIGHT NUMBER (AMERICAN 247)
  - ANOTHER FLIGHT NUMBER (AMERICAN 241)

- PILOT IS INSTRUCTED TO RESPOND TO ATC CALL INVOLVING PROBES AS QUICKLY AND ACCURATELY AS POSSIBLE

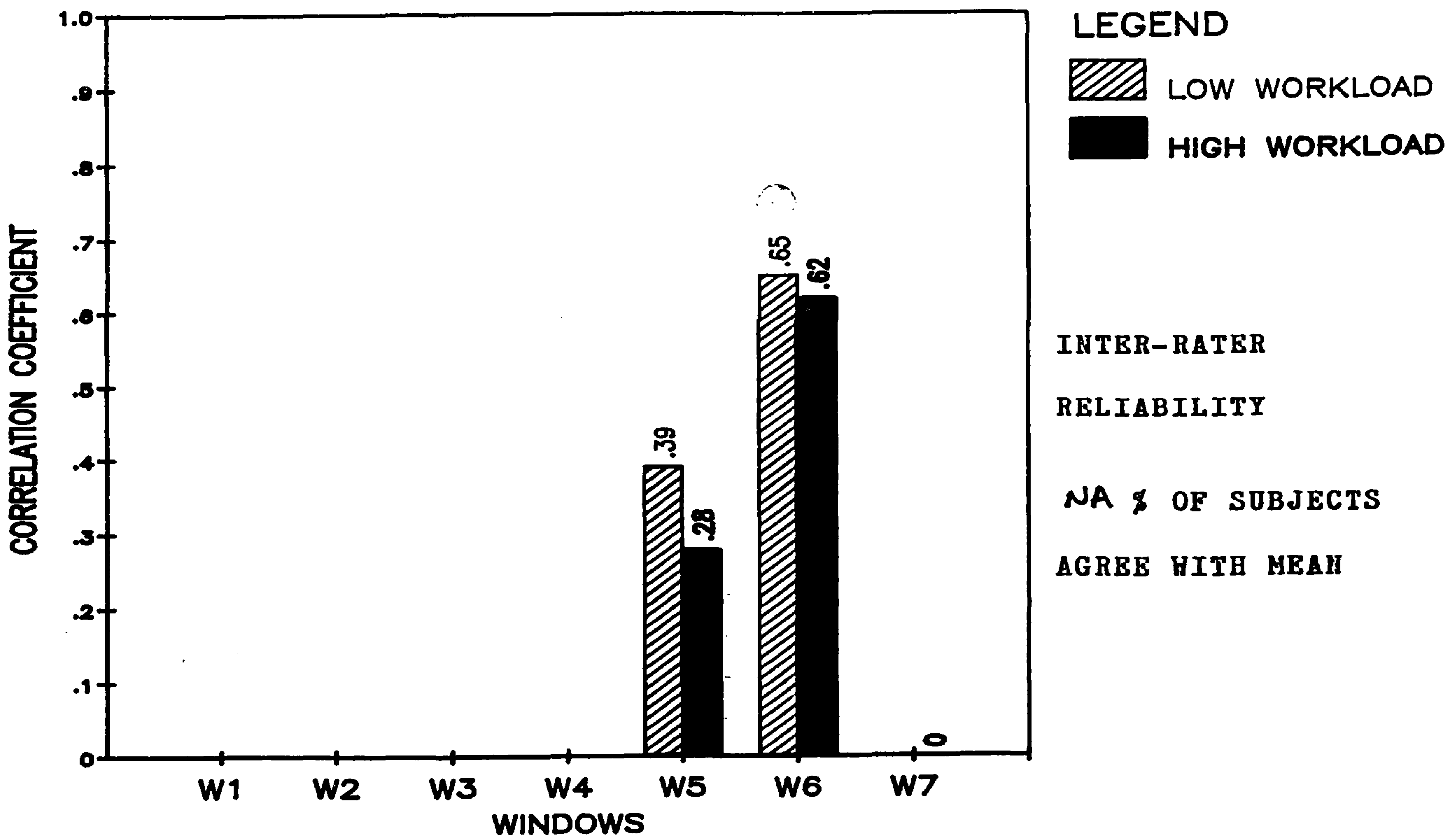
- PILOT RESPONSE IS TO TOGGLE PUSH TO TALK SWITCH (PTT)

RESPONSE TIME

- LENGTH OF TIME IN SECONDS IT TAKES PILOT TO RESPOND TO PROBE


MEAN SCORES
SECONDARY TASK
RESPONSE TIME
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD NA / 21
HIGH WORKLOAD NA / 21
RESPONSE TIME
4.0
3.5
3.0
2.5
2.0
1.5
1.0
2.15
2.29
2.71
2.93
3.09
3.19
3.15
3.39
2.69
2.84
2.74
3.25
2.73
3.29
W1
W2
W3
W4
W5
W6
W7
WINDOWS

TEST–RETEST RELIABILITY
SECONDARY TASK RESPONSE TIME
(DF ≥ 10)



INTER-RATER RELIABILITY

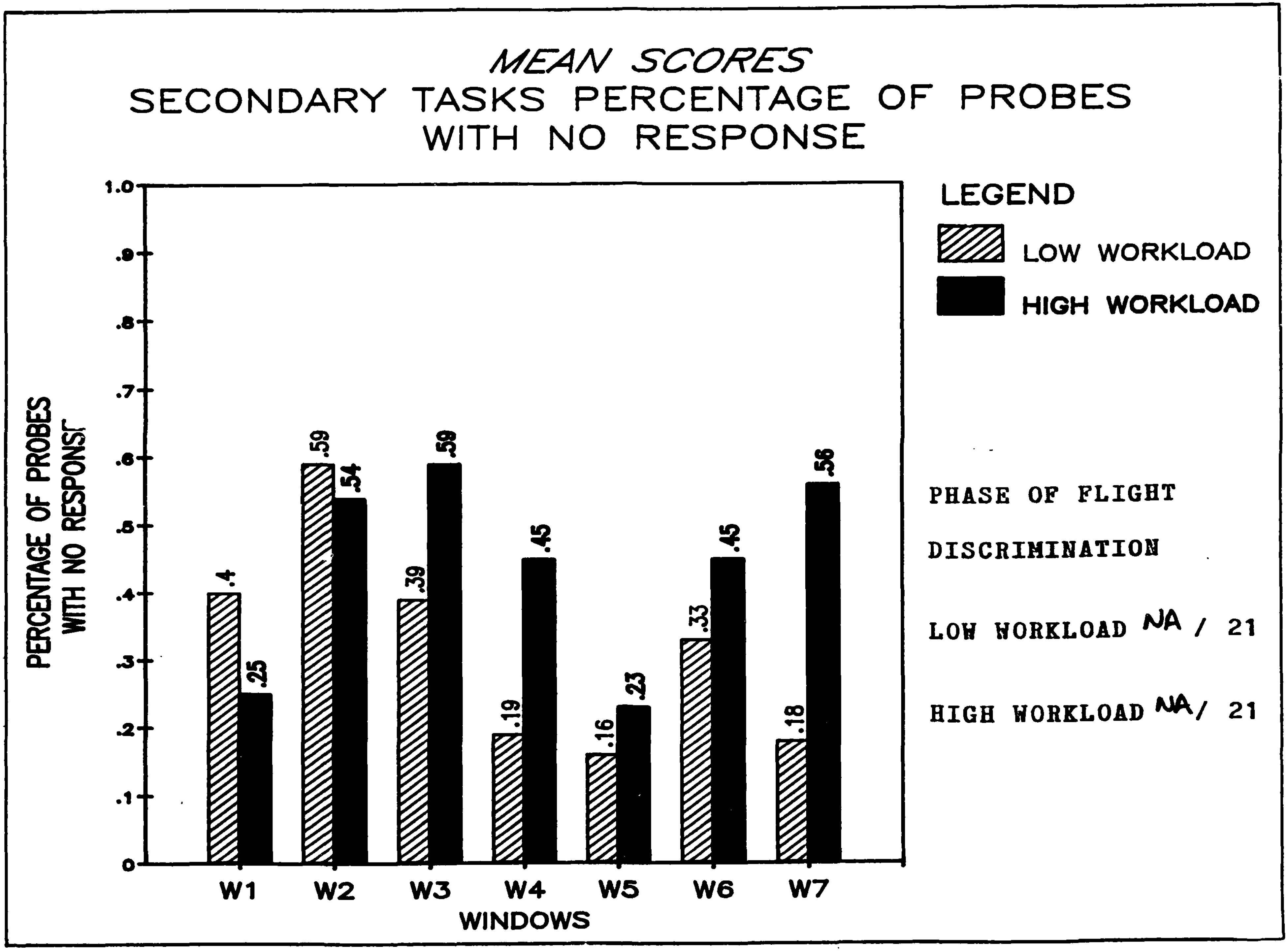
NA % OF SUBJECTS AGREE WITH MEAN

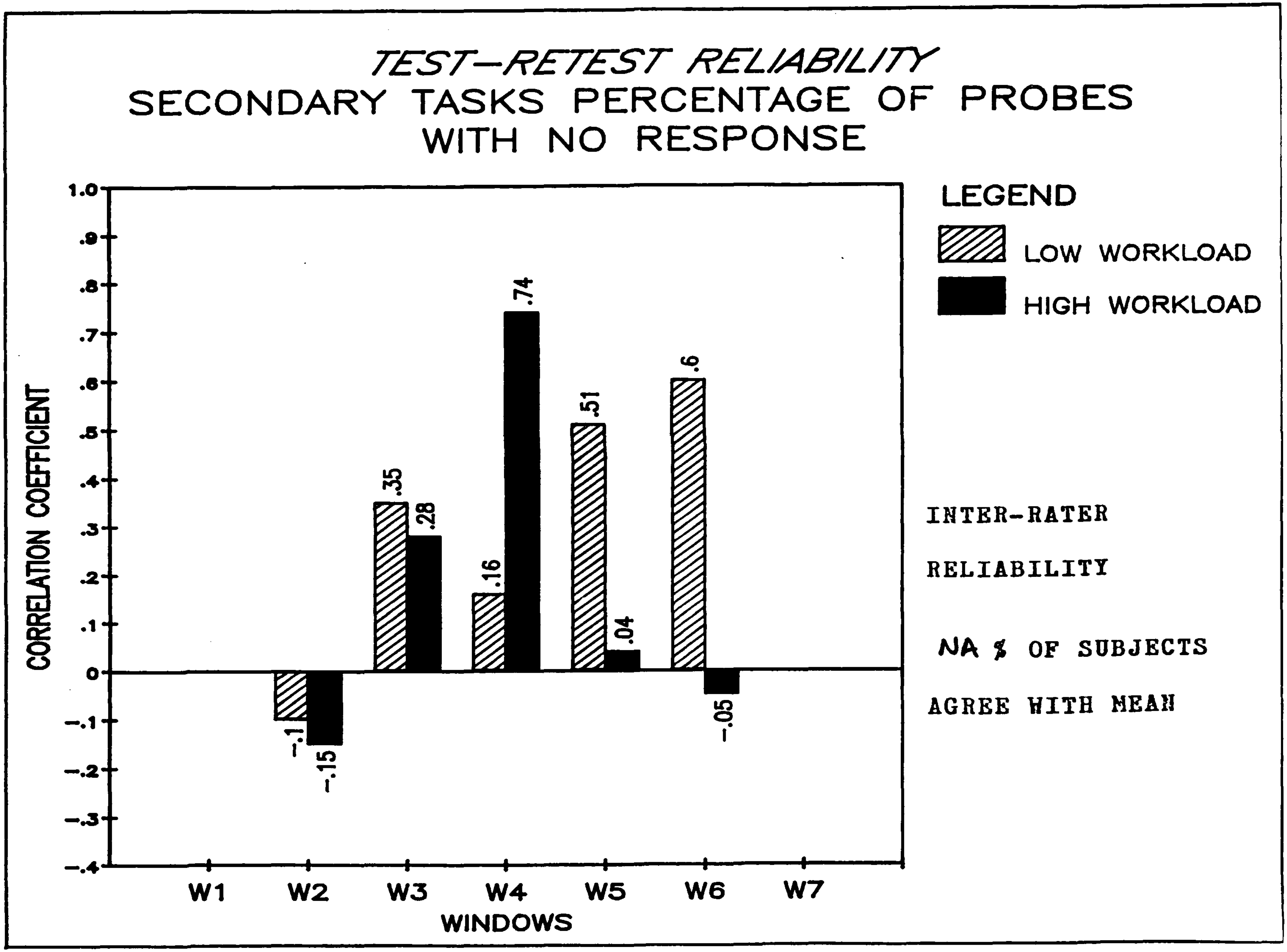
SECONDARY TASK

- TWO 'FLIGHT NUMBERS' ARE DESIGNATED POSITIVE PROBES
  - PILOT'S OWN FLIGHT NUMBER (AMERICAN 247)
  - ANOTHER FLIGHT NUMBER (AMERICAN 241)
- PILOT IS INSTRUCTED TO RESPOND TO ATC CALL INVOLVING PROBES AS QUICKLY AND ACCURATELY AS POSSIBLE
- PILOT RESPONSE IS TO TOGGLE PUSH TO TALK SWITCH (PTT)

PROBE ACCURACY

- PERCENTAGE OF PROBES NOT RESPONDED TO OUT OF TOTAL NUMBER OF PROBES


MEAN SCORES
SECONDARY TASKS PERCENTAGE OF PROBES WITH NO RESPONSE
PERCENTAGE OF PROBES WITH NO RESPONSE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.4
.25
.59
.54
.39
.59
.19
.45
.16
.23
.33
.45
.18
.56
W1
W2
W3
W4
W5
W6
W7
WINDOWS
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
PHASE OF FLIGHT
DISCRIMINATION
LOW WORKLOAD NA / 21
HIGH WORKLOAD NA / 21


TEST—RETEST RELIABILITY
SECONDARY TASKS PERCENTAGE OF PROBES
WITH NO RESPONSE
LEGEND
LOW WORKLOAD
HIGH WORKLOAD
INTER-RATER
RELIABILITY
NA % OF SUBJECTS
AGREE WITH MEAN
CORRELATION COEFFICIENT
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
−.1
−.2
−.3
−.4
−.1
−.15
.35
.28
.16
.74
.51
.04
.6
−.05
W1
W2
W3
W4
W5
W6
W7
WINDOWS

PERFORMANCE MEASURES

SUMMARY

	WHEEL	STICK	PEDAL	STRT	STPA
VALIDITY					
WORKLOAD DISCRIMINATION					
DIFFERENCES BETWEEN LOW AND HIGH WORKLOAD FLIGHT?	N/A	N/A	N/A	N/A	N/A
LOW-HIGH DIFFERENCES? (7 POSSIBLE)	5	4	0	1	0
PHASE-OF-FLIGHT DISCRIMINATION					
DIFFERENCES BETWEEN PHASE-OF-FLIGHT? **(LOW)**	N/A	N/A	N/A	N/A	N/A
PHASE-OF-FLIGHT DIFFERENCES? (21 POSSIBLE)	N/A	N/A	N/A	N/A	N/A
DIFFERENCES BETWEEN PHASE-OF-FLIGHT? **(HIGH)**	YES	YES	YES	N/A	N/A
PHASE-OF-FLIGHT DIFFERENCES? (21 POSSIBLE)	10	9	11	N/A	N/A
RELIABILITY					
TEST-RETEST CORRELATIONS: DAY 1 TO DAY 2 (14 POSSIBLE)	11	10	6	1	0
INTER-RATER AGREEMENT: EACH PILOT TO GROUP AVERAGE	N/A	N/A	N/A	N/A	N/A

ANALYTIC ASSESSMENT TECHNIQUE

The analytic assessment technique used was Time Line Analysis (TLA). TLA computes the ratio of time required, that is, execution time, to time available throughout a mission scenario.

TLA provides the capability to analyze complete operating scenarios in which one or more operators perform specified procedures, each of which is a sequence of individual tasks, within specified time intervals, over a prolonged period of time. Visual, manual, verbal, auditory and cognitive workload estimates are made for each task, procedure, phase and for the entire scenario. Analysis was performed on the Captain's tasks only.

The Time Line Analysis task was used to identify high and low task demand levels. For instance, all TLA channels (visual, manual, auditory, verbal and cognitive) showed a higher workload level in the climb phase of flight when the autopilot failed to engage. When the engine and hydraulic systems failed, a higher level of workload was again reflected by TLA. This higher workload level then continued through the rest of the high workload flights because the pilot was handflying the aircraft with the failure conditions to a high speed landing. In contrast, task demands in the takeoff segment of flight for all scenarios were identical, so the workload level for the takeoff segment was hypothesized to be the same for both the high and low workload scenarios.

As shown by the data, TLA accurately reflects the task demands of the scenarios. TLA can be a very useful tool to identify periods of high and low task demands.

Following are the transparencies presented on the Time Line Analysis assessment performed.

Analytical Workload Measurement Timeline Analysis

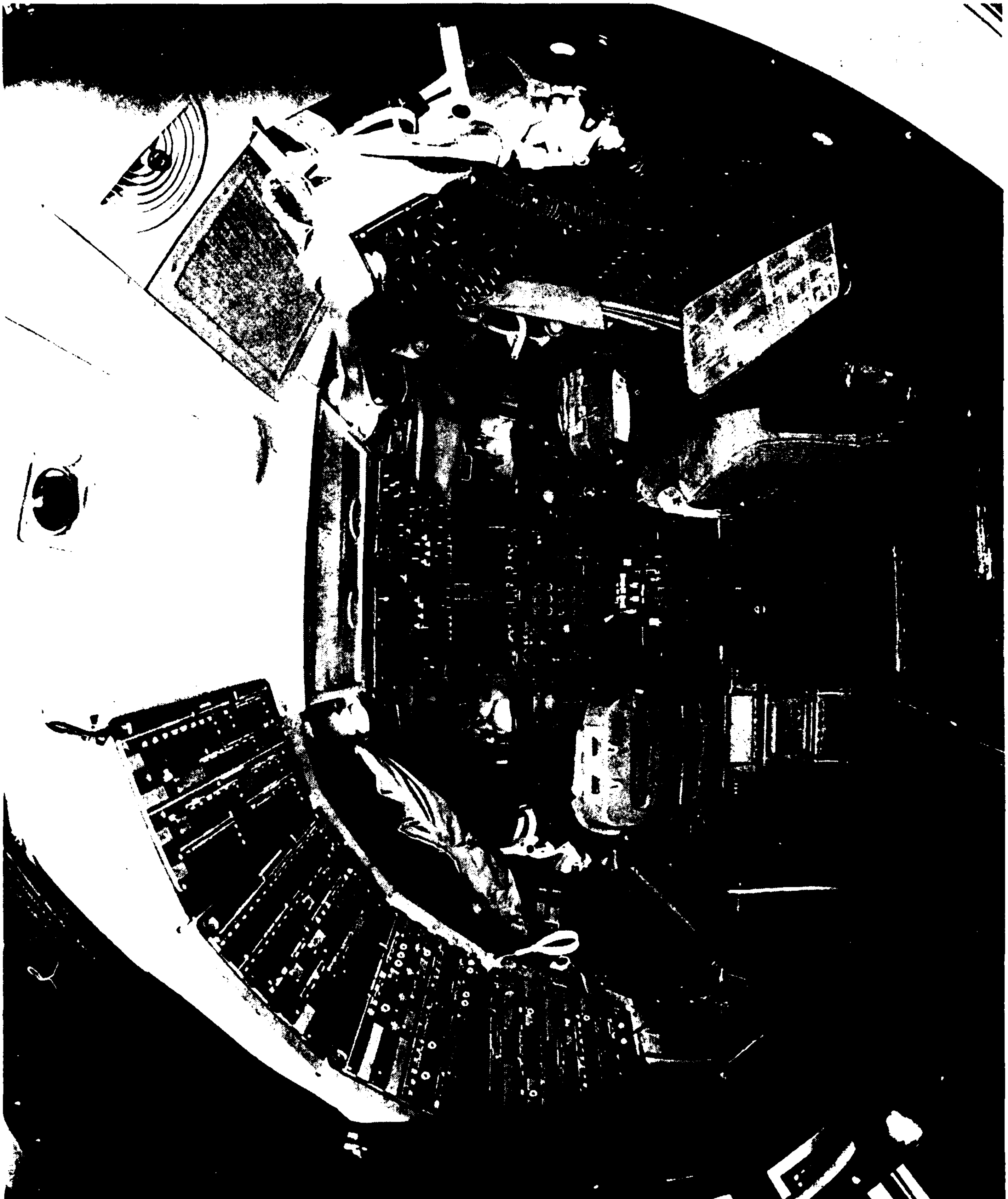
Aileen L. Logan
Boeing Commercial Aircraft Company
Seattle, Washington

EL1167.07

Timeline Analysis (TLA)

Computes the ratio of time required to time available throughout the flight mission scenario.

AL1167.31



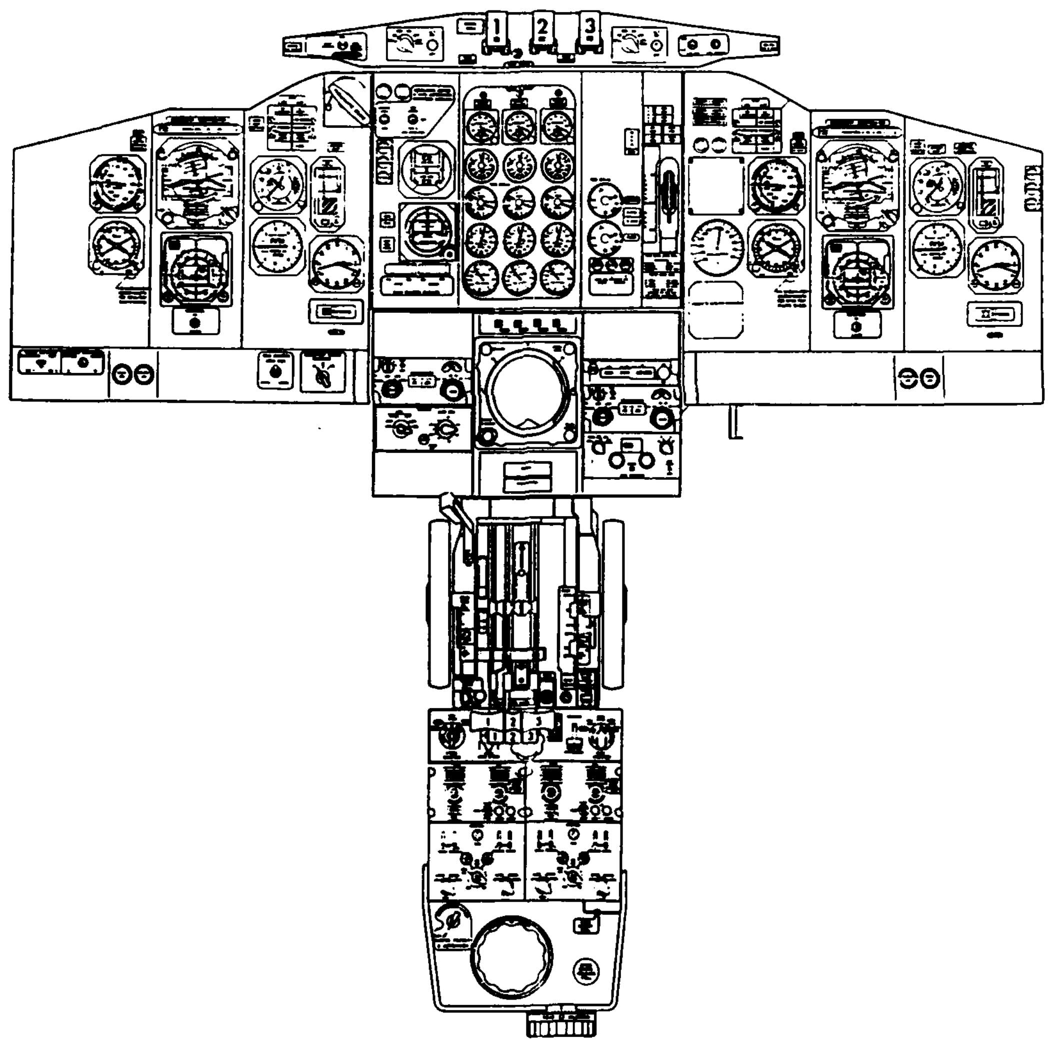
Timeline Analysis

Geometric Data Base

- Index/control records
  - Number of panels
  - Number and types of controls and indicators
  - Control and indicator type descriptions
  - Eye, look, and hand reference points
  - Auditory message count and type
  - Verbal message types and type descriptions
- Panel configuration records
  - Control and indicator data

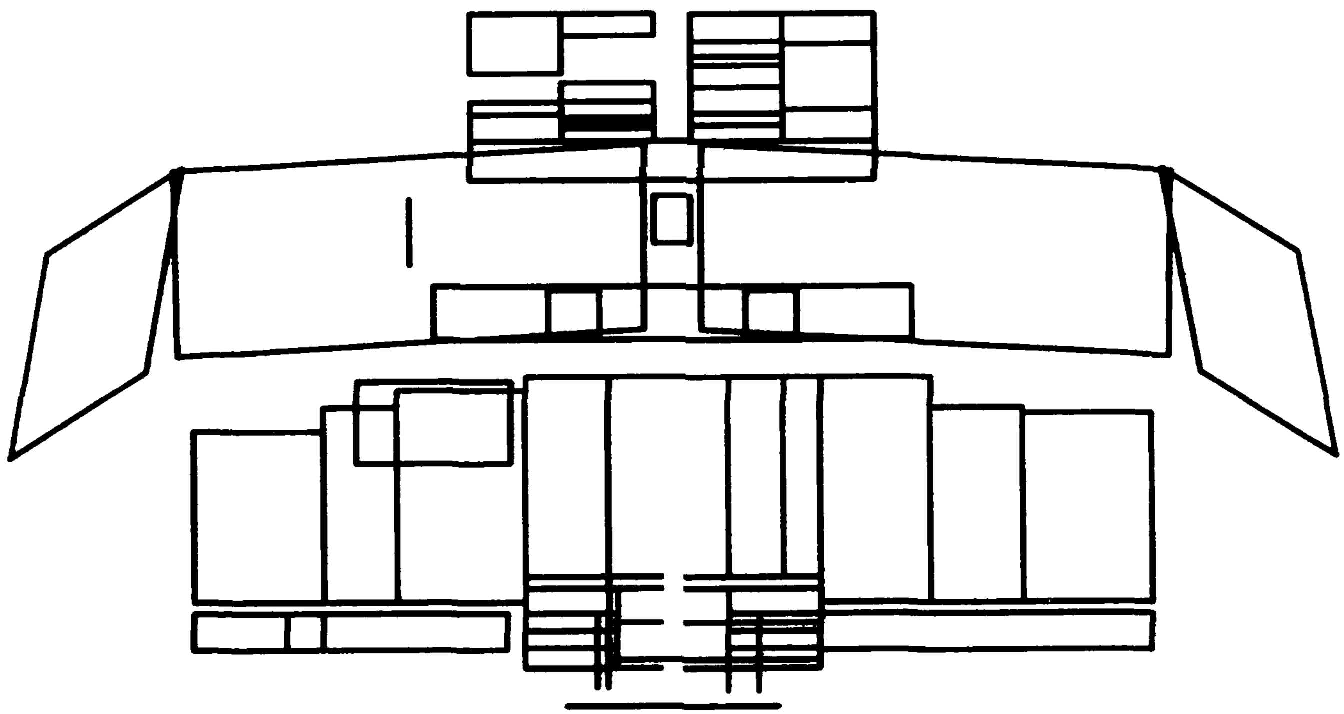
AI1167.25

Flight Deck Geometric Data Base



Timeline Analysis
Flight Deck Geometric Data Base

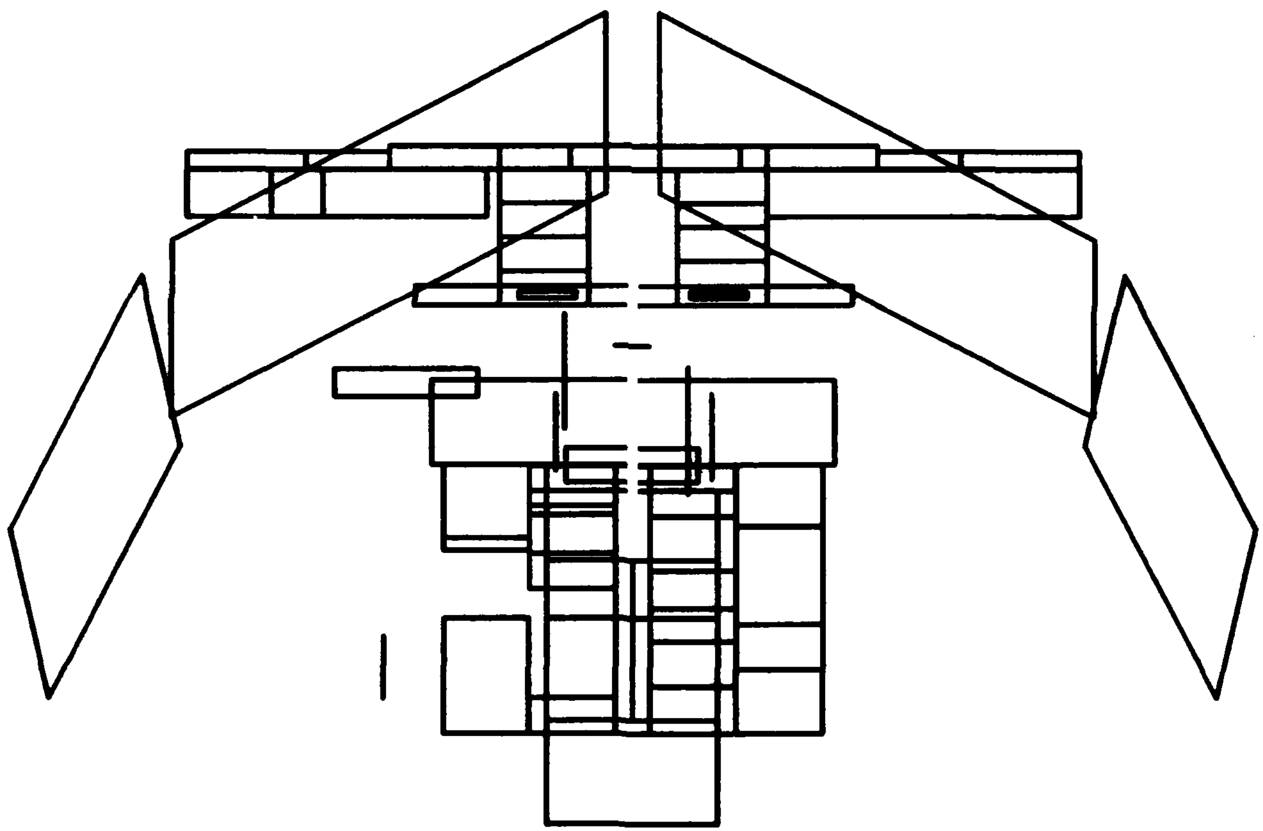
Boeing 727-232 (Delta)



BL1167.08

Timeline Analysis
Flight Deck Geometric Data Base

Boeing 727-232 (Delta)



BL1167.09

Timeline Analysis

Example of Flight Mission Scenario File

CR	1 Captain			
FP	1 Takeoff			
PR	0001.30	Start takeoff run	0001.30	0001.45
ST				

- Hears brake lever release
- Senses airplane start to roll
- Advances thrust levers for number 1 engine for *initial acceleration and allows* even engine spoolup
- Advances thrust levers for number 2 engine for initial acceleration and allows even engine spoolup
- Looks at engine EPR indicators for even engine acceleration (engines 1, 2, and 3)
- Continues thrust levers to approximate takeoff setting (engines 1, 2, and 3)
- Check engine EPR indicators for takeoff bug setting (engines 1, 2, and 3)
- Sees F/O adjust thrust levers for number 1, 2, and 3 engines

AL1167.35

Timeline Analysis (Continued)

Example of Flight Mission Scenario File

- Looks through left front window along runway centerline
- Maintains light forward pressure on column
- Keeps wings level
- Hears F/O "80 kn"
- Looks at airspeed display
- Says, "Check"
- Continues looking out forward window

CD 8101,13201,7104,7204,239,235,7111,7211,239,235,7111S,7211S,13302,180,
13302,30004,114,20004,13302

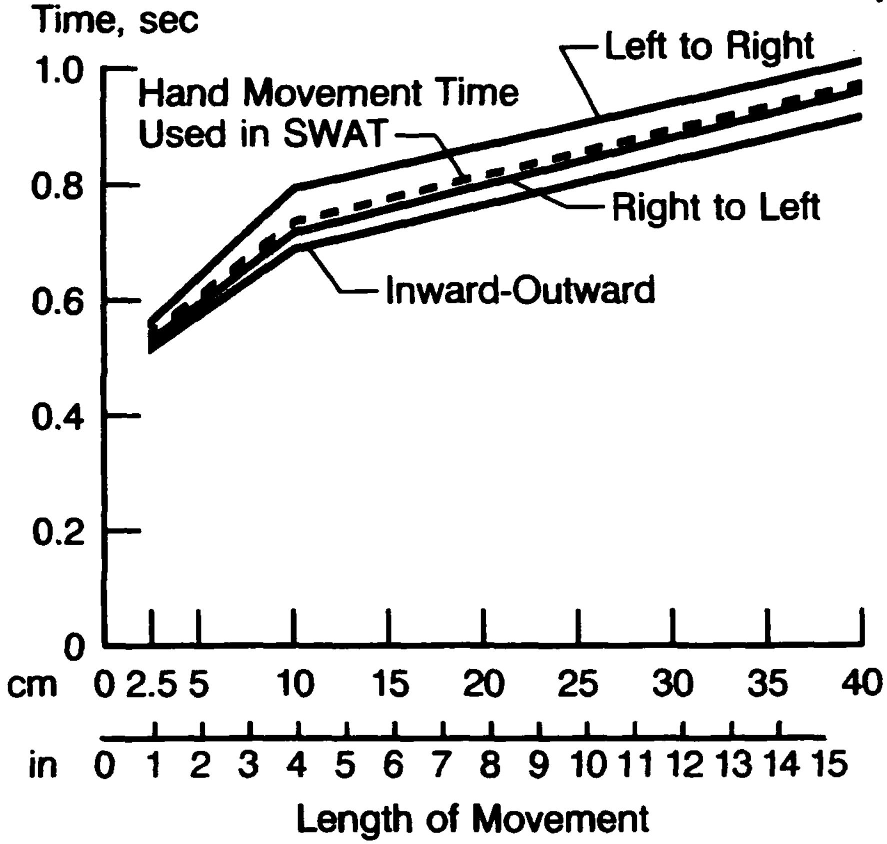
PR 0001.53 Rotation 0001.46 0002.05

ST
- Hears F/0 "V one"
- Hears F/O, "Rotate"
- Looks at airspeed
- Begins to apply back force on control wheel
- Rotates to liftoff attitude
- Complete rotation to desired attitude with reference to attitude indicator
- Senses liftoff
- Checks altimater for positive rate of climb

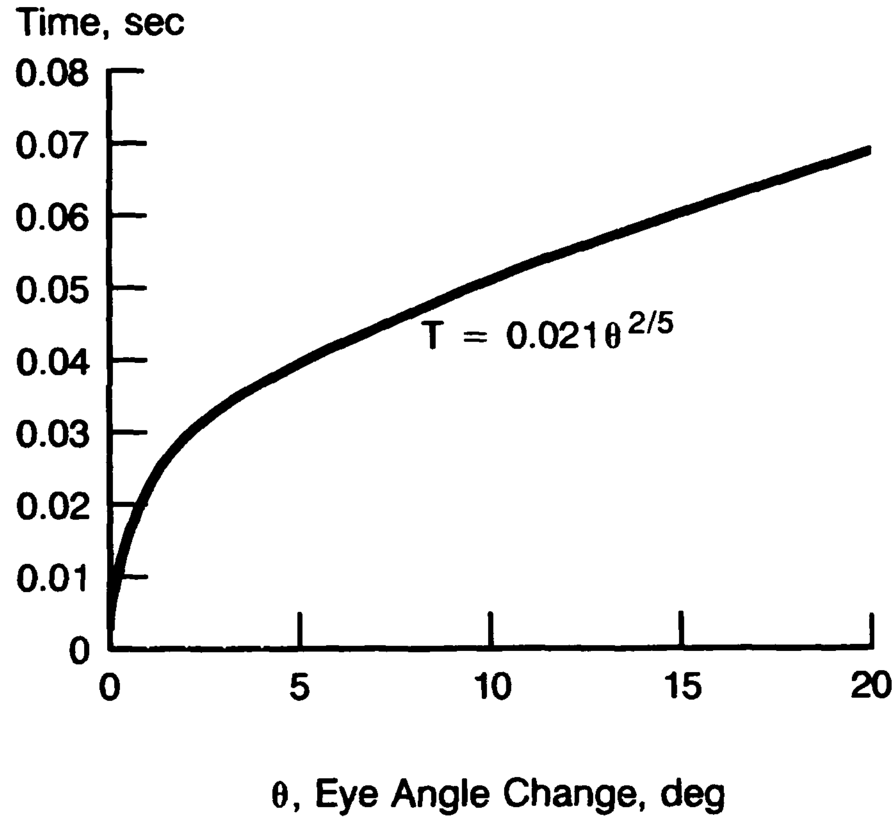
AL1167.36

Timeline Analysis

Time Requirements



Horizontal Positioning Movements Versus Length of Movement



Eye Motion Versus Angle-of-Eye-Movement Change

BL1167.07

Timeline Analysis

- Evaluates for each crew member:
  - Hand activity time
  - Eye activity time
  - Cognition time
- Estimates the times a crew member is occupied by:
  - Visual task
  - Motor task
  - Cognitive task
  - Verbal task
  - Auditory task

AL1167.30

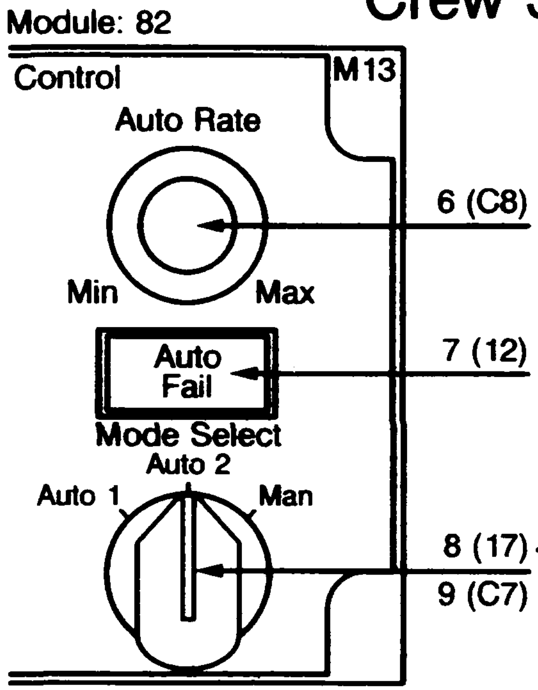
Timeline Analysis

- Requires
  - Flight deck geometric data base
    - Complete task code data
    - Complete hand and eye reference point data
  - Flight mission scenario file
    - Detailed task breakdown for full flight

AL1167.26

Timeline Analysis

Crew Station Description, Example



Each device is characterized in terms of its:

- Aircraft location
- Workload cost (dwell time)
- Complexity score

Workload Cost Table (Example)

Estimated Workload Cost (Dwell Time, sec)		Workload Type Code
4.04	CIRCULAR SCALE GAUGES (QUANTITATIVE READING)	13
3.30	CIRCULAR SCALE VALVE POSITION	14
3.67	LINEAR SCALE	15
1.50	DIGITAL INDICATOR	16
0.75	MONITOR SWITCH POSITION	17
2.73	CIRCULAR SCALE GAUGES (QUALITATIVE READING)	18

Example Data Card Format

Device Code Number	Workload Type Code	Location Coordinates	Complexity Score (bits)	Device Description
8208	1 7	2.20 0.38	1.58	PRESSURE MODE SEL MONITOR

BL1167.04

Timeline Analysis

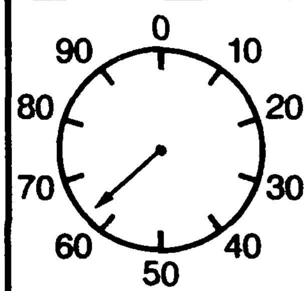
Device Complexity Measure

Definition

Device complexity is the number of binary digits required to encode the possible number of alternatives associated with the device

Device Complexity = $\log_2$(Number of Alternatives) bits

Examples

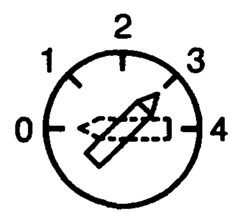


Instrument Reading

Number of Alternatives = $\dfrac{\text{Range}}{(0.5)(\text{Scale Unit})}$

Device Complexity = $\log_2 \dfrac{10}{(0.5)(1)} = 4.35$ bits

Rotary Selector Switch



Discrete Control

Number of Alternatives = 5

Device Complexity = $\log_2 (5) = 2.32$ bits

BL1167.01

Timeline Analysis
Device Complexity Measure

- Device complexity score is based upon the information content of the possible states that the device presents
- The device complexity score serves as the basis for estimating *cognitive* workload time
- Procedure complexity is the sum of device complexity scores for all steps of a procedure

AL1167.37

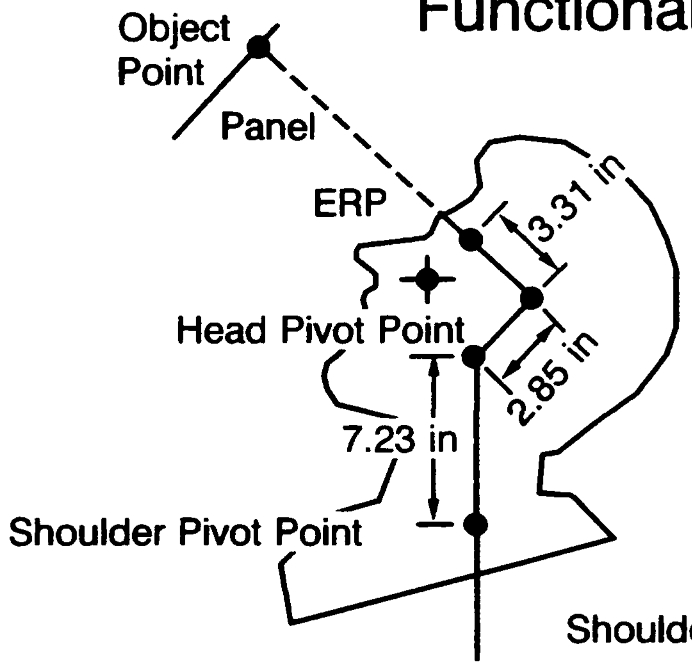
Timeline Analysis
Workload Measures

- **Motion**
  - Eyes - Total degrees traveled
  - Hands - Total inches traveled
- **Time** — Total time to execute task (transit + dwell)
- **Tasks** — Number of actions required to execute a task
- **Procedure Complexity** — Summation of device complexity associated with a task

AL1167.29

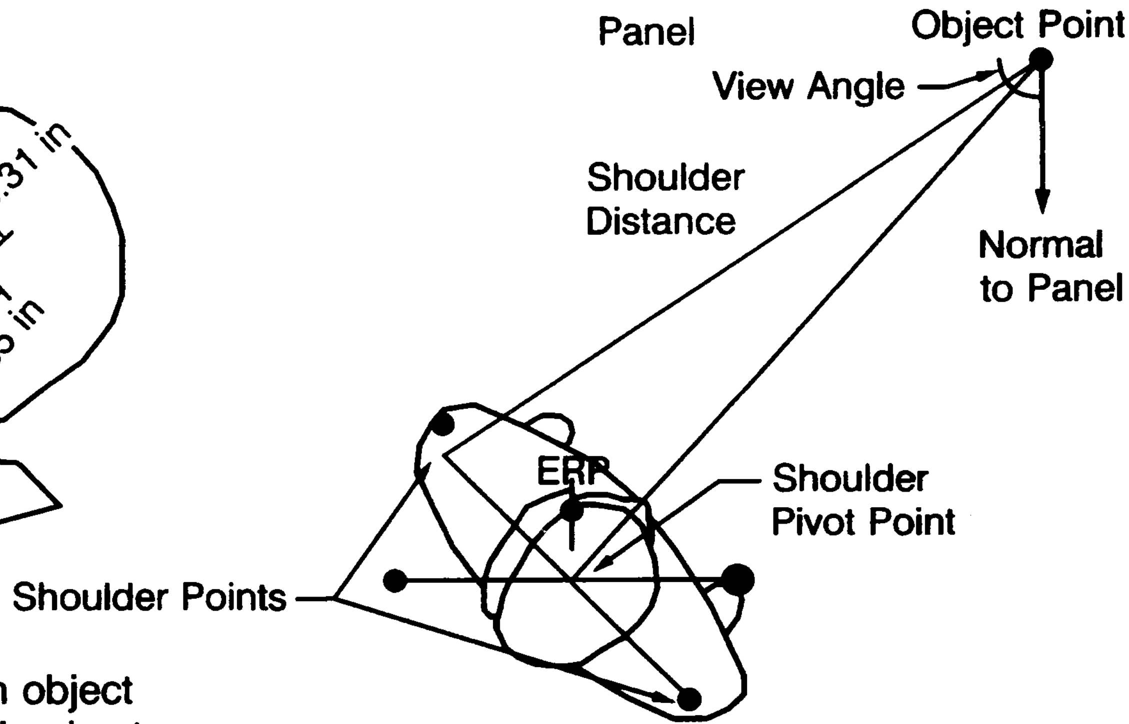
Timeline Analysis

Functional Reach and Vision



When observer looks at an object point above the ERP, rotation is at the head pivot point. Below the ERP, rotation is at the shoulder pivot point

Vertical Plane



Horizontal Plane

BL1167.05

Timeline Analysis

$$\text{Percent of Window Time} = \frac{\text{Time Used}}{\text{Length of Window}}$$

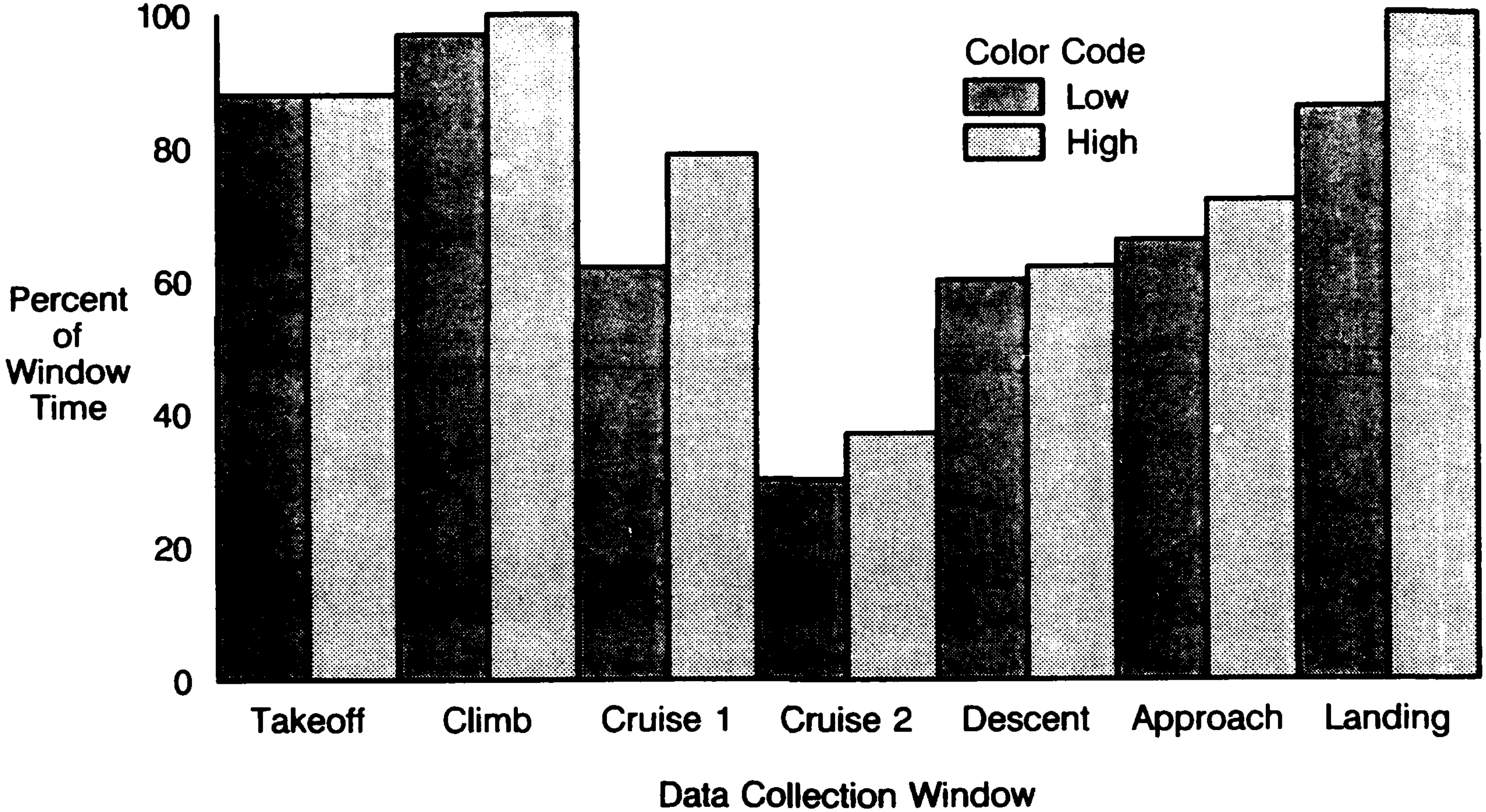
$$\text{Low Workload Data} = \frac{(\text{Low SMF to SFO}) + (\text{Low SFO to SCK})}{2}$$

$$\text{High Workload Data} = \frac{(\text{High SMF to SFO}) + (\text{High SFO to SCK})}{2}$$

EL1167.06

Timeline Analysis

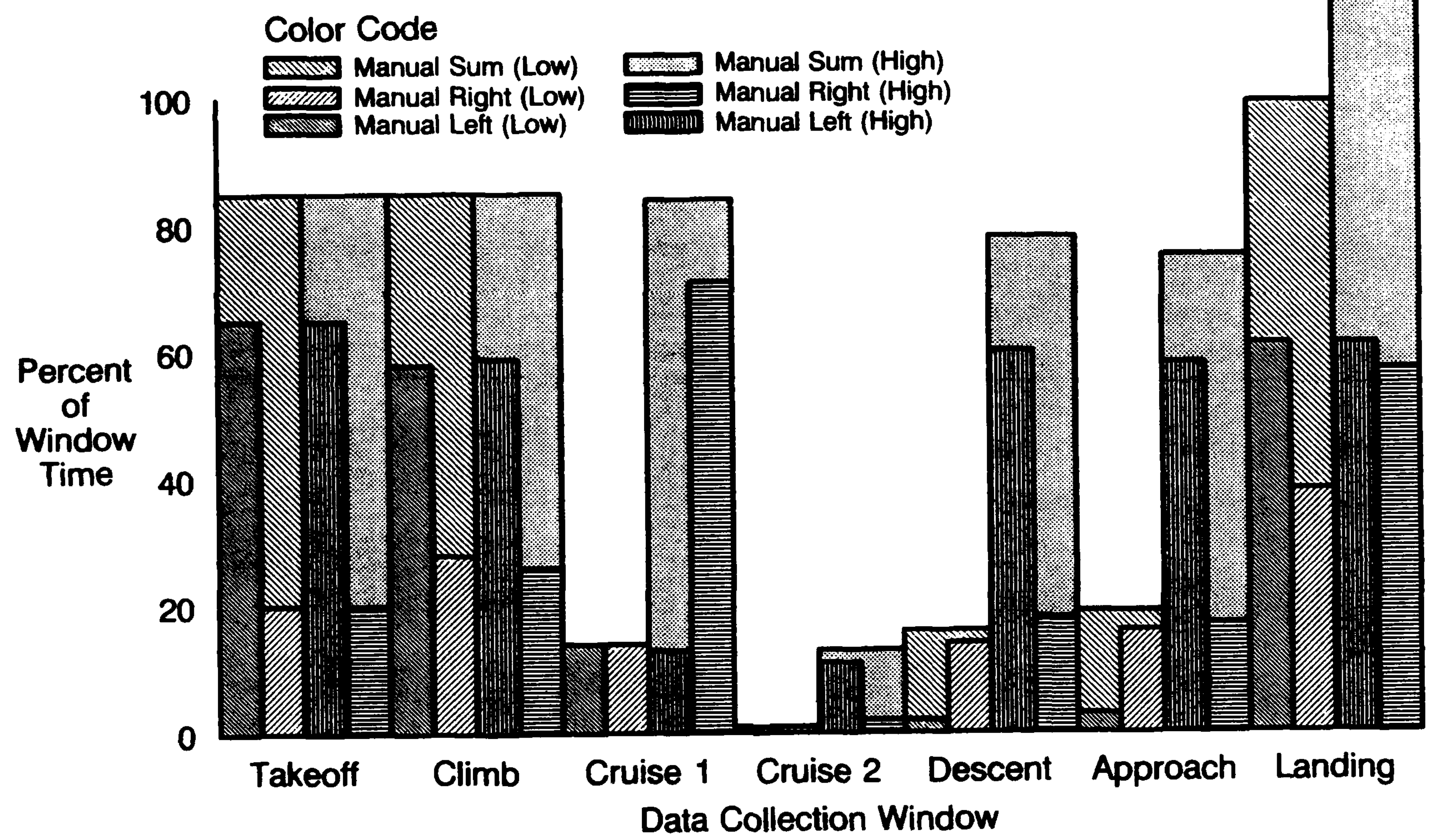
Visual Data



EL1167.05

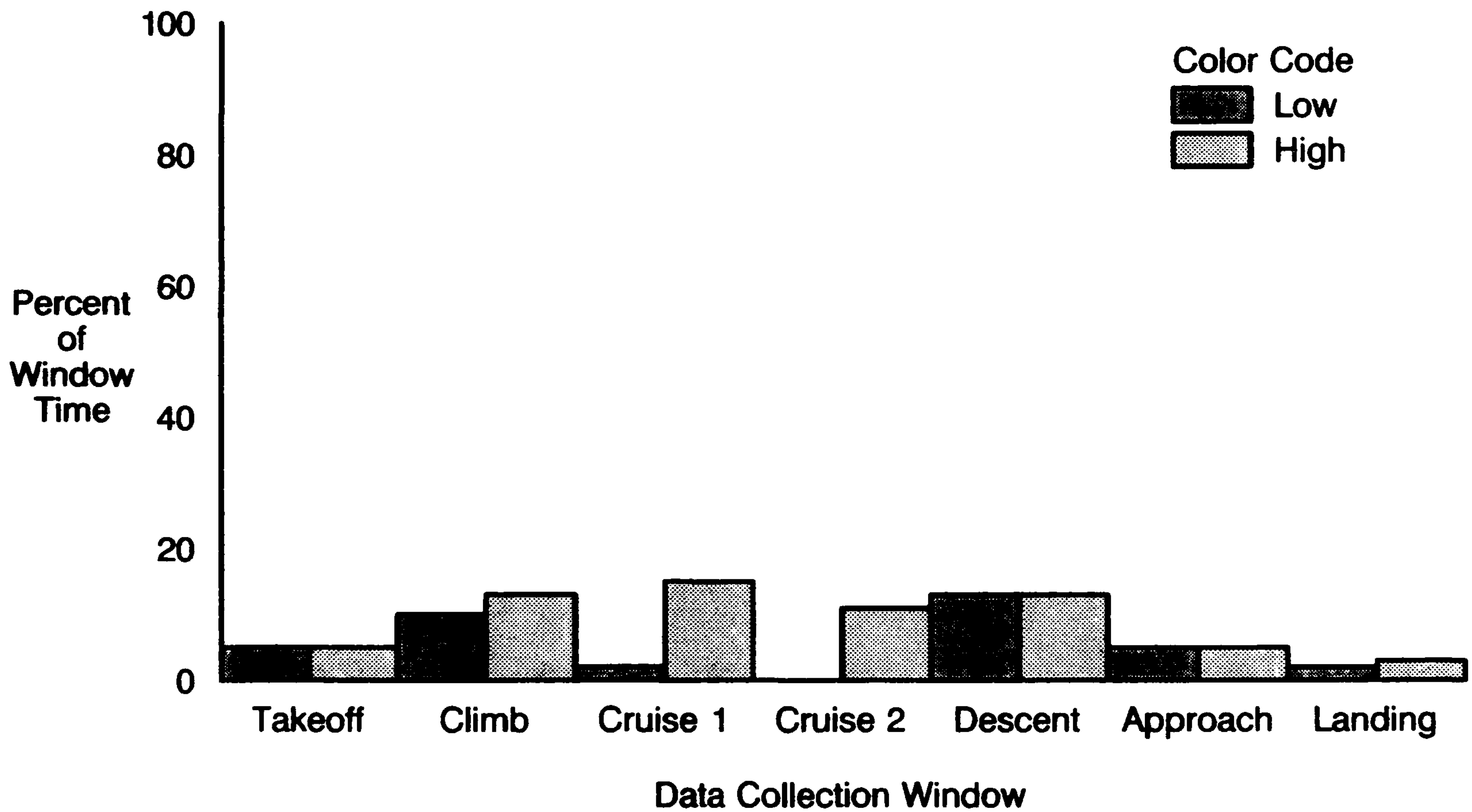
Timeline Analysis

Manual Data



EL1167.04

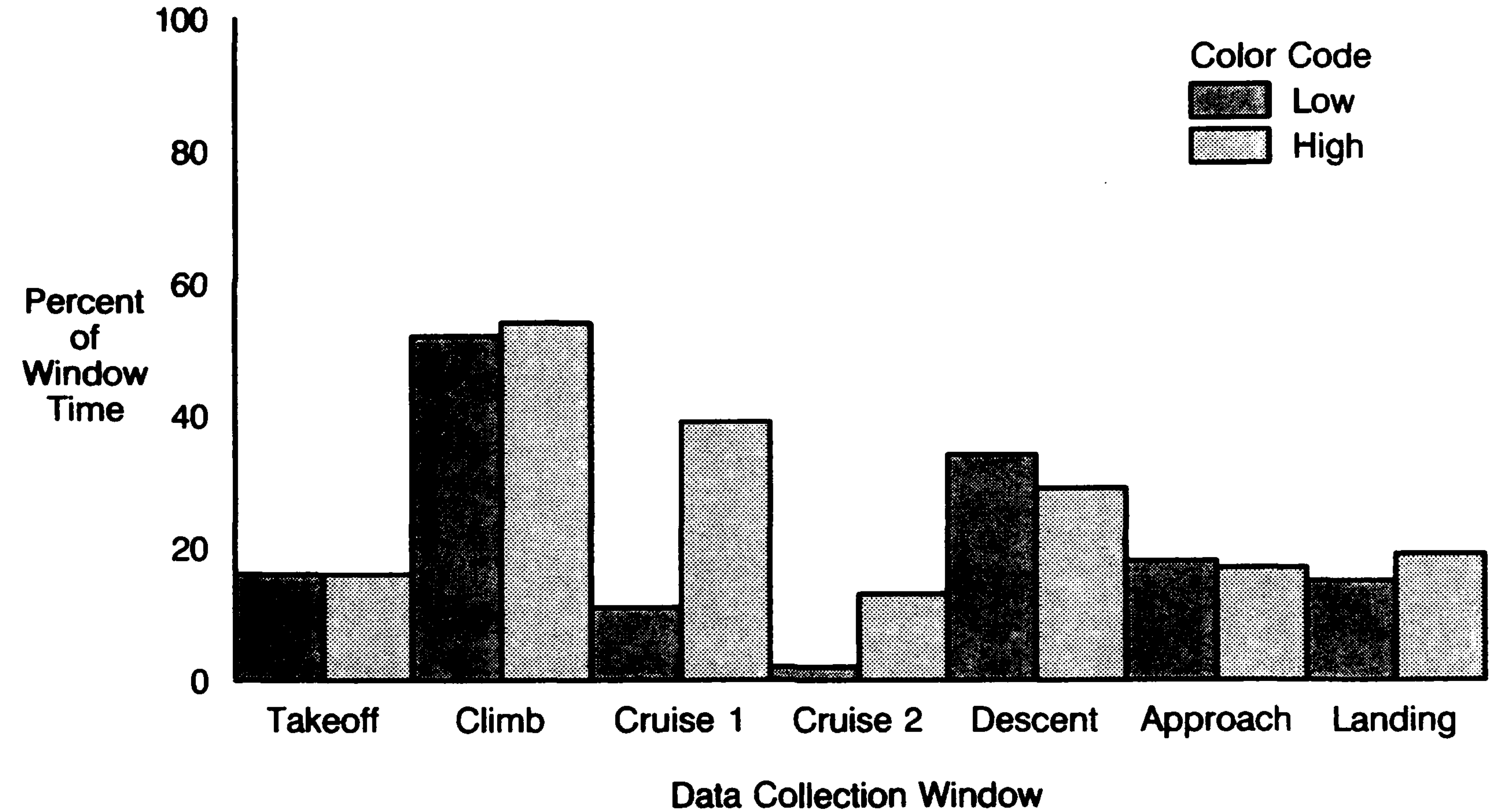
Timeline Analysis
Verbal Data



EL1167.03

Timeline Analysis

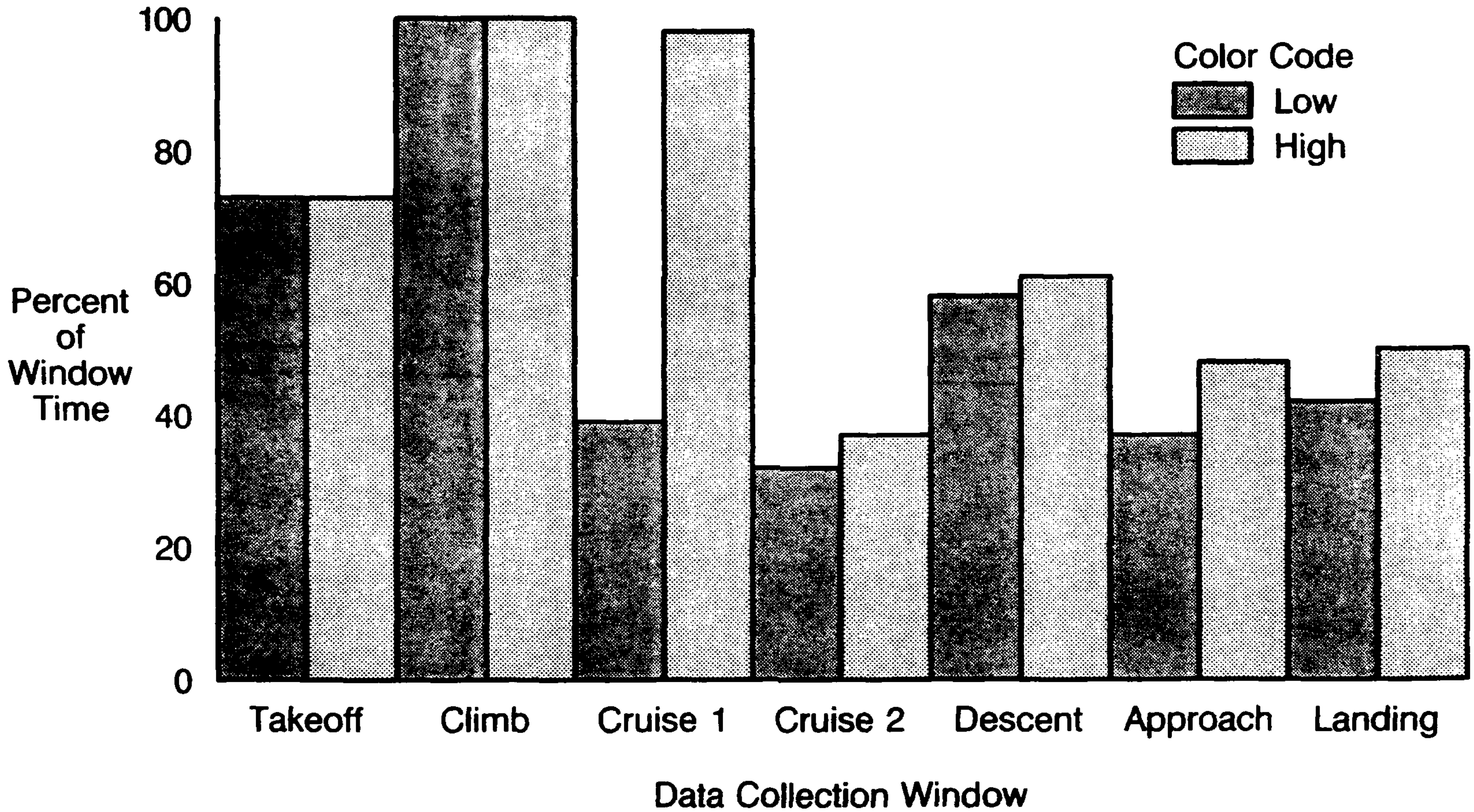
Auditory Data



EL1167.01

Timeline Analysis

Cognitive Data



EL1167.02

COMPARISON OF WORKLOAD MEASURES

DESCRIPTION OF CORRELATION MATRIX AND FACTOR ANALYSIS

A correlation matrix was created for all the workload assessment techniques presented at the workshop including: subjective, physiological, performance, and time-line analysis. The average score across subjects for the 14 different measurement periods (seven measurement windows for the high and low workload flights) were used for the correlation matrix. The time-line analysis yields a single score, for each body channel, for each of the 14 measurement windows. The workload scores were then used to compute the correlation matrix.

The purpose of the correlation matrix is to evaluate how much the workload scores "overlap". If two workload measures can both discriminate levels of workload and show reliability but are not correlated then the two measures are thought to be evaluating different aspects of workload.

In addition to the correlation matrix a principal components analysis (factor analysis) was performed to try to reveal underlying common dimensions among the various workload measures. The same 14 measurement window were used for the principal components analysis. A "loading" for the factor analysis is a number between 1.0 and -1.0. The factor loading can be thought of in terms of an absolute value in that a score of 0.85 or -0.85 loads highly on the given factor. The closer the factor loading is to zero the less that particular workload assessment technique is associated with the given factor (factor loadings between 0.25 and -0.25 are intentionally left blank).

In addition to the correlation matrix, the factor analysis can show that two different valid and reliable workload measures assess different aspects of workload. If the workload measures show validity and reliability but load on different factors in the factor analysis, it indicates the measures are tapping different aspects of workload.

CORRELATION MATRIX

	HRM	HRSD	ABP	ARS	EBK	WHL	STK	PDL	SWAT	TLX	STRT	STRT%
HRM	1.00											
HRSD	-.58	1.00										
ABP	.48	.12	1.00									
ARS	-.54	**.73**	.20	1.00								
EBK	-.27	.38	.13	-.01	1.00							
WHL	**-.67**	**.80**	-.17	**.86**	-.01	1.00						
STK	**-.82**	**.88**	-.22	**.73**	.26	**.90**	1.00					
PDL	**-.74**	.34	-.54	-.04	.61	.17	.47	1.00				
SWAT	-.44	.45	.04	**.69**	-.01	**.68**	.55	-.09	1.00			
TLX	-.32	.37	.07	.62	-.12	.59	.46	-.20	**.97**	1.00		
STRT	-.02	.54	.51	.59	.04	.58	.44	-.33	.60	.57	1.00	
STRT%	-.20	.09	-.43	.18	-.25	.46	.25	-.05	.54	.49	.35	1.00

	HRM	HRSD	ABP	ARS	EBK	WHL	STK	PDL	SWAT	TLX	STRT	STRT%
VISUAL	-.55	.14	**-.91**	-.05	-.11	.34	.38	.54	.04	-.02	-.39	.48
MANLEFT	-.64	.10	**-.87**	.12	-.03	.36	.43	.59	.05	.03	-.41	.19
MANRIGHT	-.56	.54	-.39	.32	.11	.55	.60	.39	.49	.40	.14	.51
VERBAL	.17	-.13	-.04	.11	-.39	.09	-.13	-.47	.51	.63	.03	.31
AUDITORY	.14	-.13	-.44	-.08	-.47	.15	-.07	-.30	.21	.28	-.13	.51
COGN'TVE	-.02	-.31	**-.66**	-.26	-.42	-.01	-.12	-.04	.20	.25	-.32	.55

	VIS	MANL	MANR	VERB	AUD	COG
VISUAL	1.00					
MANLEFT	**.74**	1.00				
MANRIGHT	.64	.28	1.00			
VERBAL	.10	-.01	.21	1.00		
AUDITORY	.55	.25	.38	**.78**	1.00	
COGN'TVE	.65	.42	.49	.65	**.85**	1.00

***** Critical correlation values are r(12)=.66 or r(12)= -.66 are in bold *****

VARIABLE LABELS

HRM	Average Inter-beat Interval
HRSD	Standard Deviation for Average Inter-beat Interval
ABP	Mulder Spectral Analysis Blood Pressure component from heart rate
ARS	Mulder Spectral Analysis Respiration component from heart rate
EBK	Eye blinks per minute
WHL	Wheel control input (aileron) per minute
STK	Stick control input (aileron) per minute
PDL	Pedal control input (aileron) per minute
SWAT	Subjective Workload Assessment Technique
TLX	NASA Task Load Index
STRT	Secondary Task Reaction Time
STRT%	Probe Accuracy, to positive probes, for Secondary Task

BOEING TIME-LINE ANALYSIS

VISUAL -- Eyes
MANLEFT -- Left side of body
MANRIGHT -- Right side of body
VERBAL -- Spoken communication
AUDITORY -- Listening by flight crew
COGN'TVE-- Cognitive channel

PRINCIPAL COMPONENT ANALYSIS

SORTED ROTATED FACTOR LOADINGS (PATTERN)

		FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
RESPIRATION	4	.938			
WHEEL INPUT	6	.936			
STICK INPUT	7	.870	.357		
HR VARIABILITY	2	.826			.346
SWAT	9	.753		.527	
SEC. TASK RT	11	.706	-.545		
TLX	10	.676		.580	
HR AVG. IBI	1	-.627	-.626		-.301
BLOOD PRESS.	3		-.929	-.281	
MANUAL LEFT	14		.913		
VISUAL	13		.887	.367	
PEDAL INPUT	8		.664	-.284	.656
COGNITION	18		.437	.845	
VERBAL	16			.837	
AUDITORY	17		.253	.836	-.274
SEC. TASK %	12	.306		.674	
MANUAL RIGHT	15	.427	.371	.517	.453
EYEBLINK	5			-.318	.867
	VP	5.502	4.333	3.898	1.851

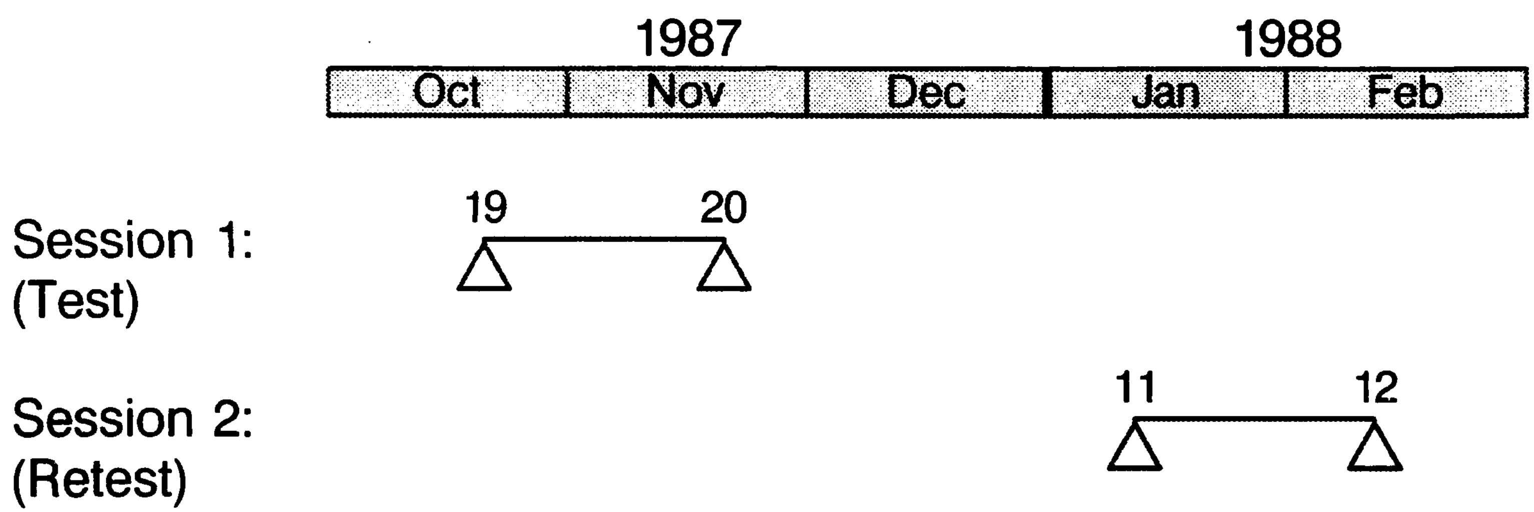
The above factor loading matrix has been rearranged so that the columns appear in decreasing order of variance explained by the factors. The rows have been rearranged so that for each successive factor, loadings greater than 0.500 appear first. Loadings less than 0.25 have been blanked.

Description of Full-Mission Simulation Testing

Diane L. Sandry-Garza
Boeing Commercial Airplane Company
Seattle, Washington

C1167.02

Schedule
Full-Mission Simulation
Testing at NASA-Ames



D1167.19

Simulation Facility

- NASA - Ames (MVSRF)
- Boeing 727 motion-base simulator
- High level of fidelity
- ATC simulation

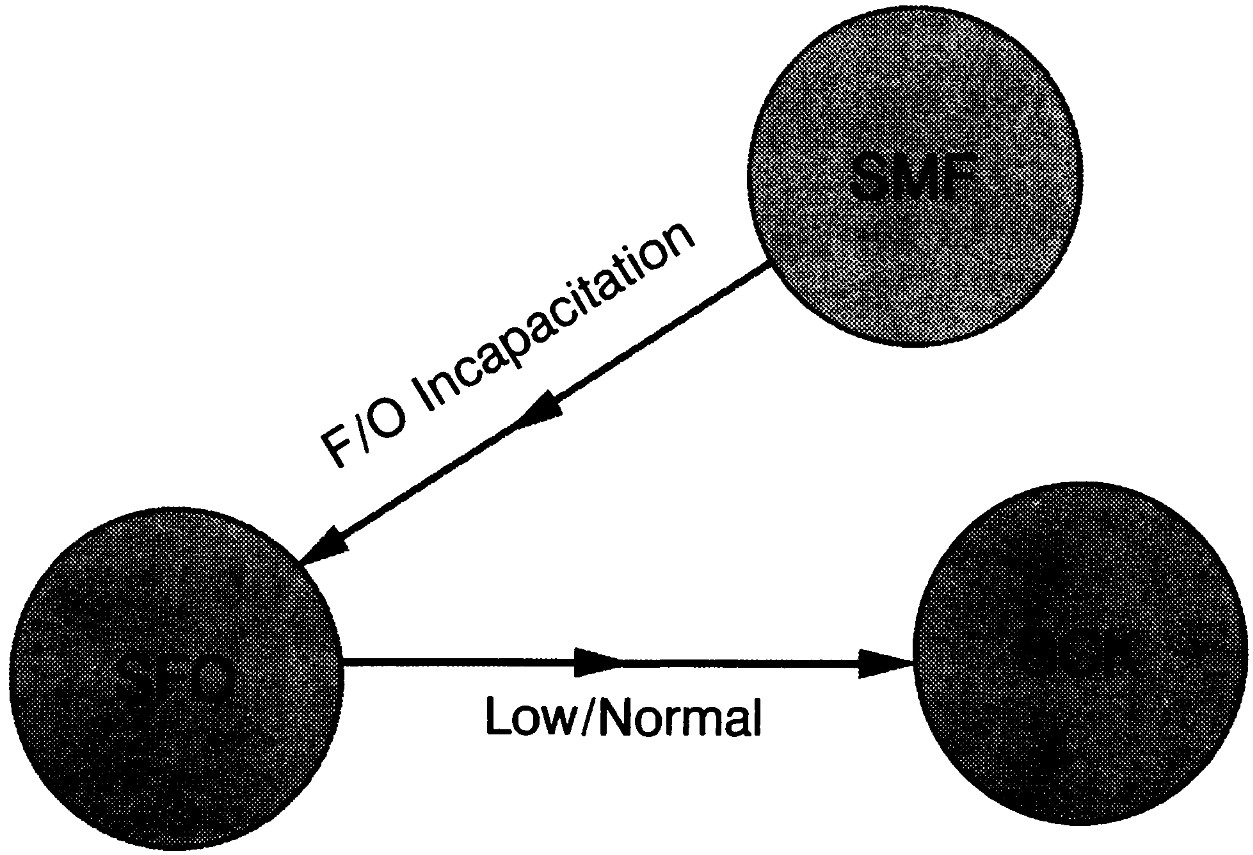
A1167.01

Subjects

- FAR qualified and current 727 airline pilots
- Captain (data collection)
- Confederates
- Representative of population

A1167.02

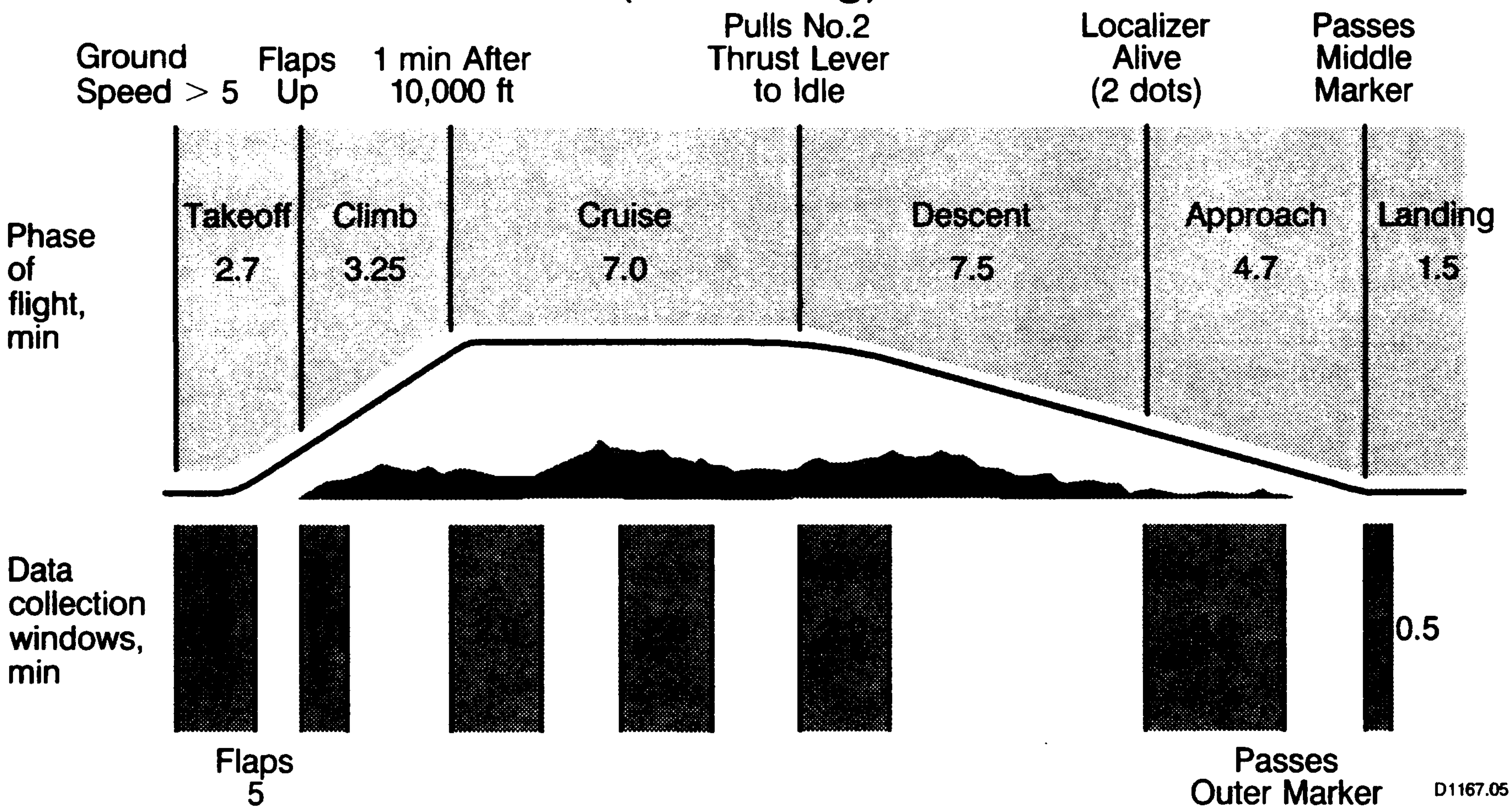
Full-Mission Simulation Scenarios
(Short Legs)



D1167.06

Full-Mission Simulation
Phases of Flight and Data Collection

(Short Leg)



Full-Mission Simulation
(Short Legs)

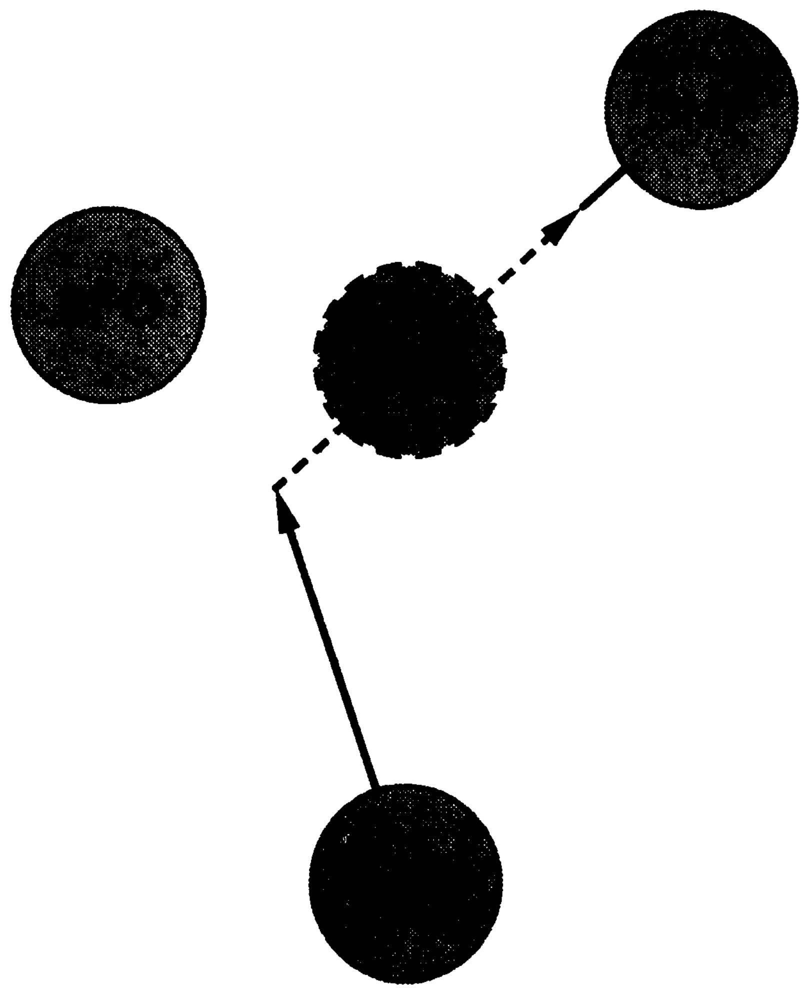
Data Collection Windows

Window	Open	Close
Takeoff	E.P.R. 1.50	Flaps 5
Climb	Flaps up	1 min later
Cruise 1	1 min after 10,000 ft	2 min later
Cruise 2	3 min after window 3 closes	2 min later
Descent	Number 2 throttle to idle	2 min later
Approach	Localizer alive (2 dots)	Outer marker
Landing	Middle marker	30 sec later

D1167.13

Full-Mission Simulation Scenario

(High Workload Leg)



D1167.07

Full-Mission Simulation
(High Workload Leg)

Data Collection Windows

Window	Open	Close
Takeoff	E.P.R. 1.50	Flaps 5
Climb	Flaps up	1 min later
Cruise 1	1 min after 30,000 ft	2 min later
Cruise 2	3 min after window 3 closes	2 min later
Descent	Number 2 throttle to idle	2 min later
Approach	Localizer alive (2 dots)	Outer marker
Landing	Middle marker	30 sec later
Missed approach	1,500 ft after middle marker	2 min later
"A" System hydraulic malfunction	1 min after 6,800 ft	2 min later
Approach	Localizer alive (2 dots)	Outer marker
Landing	Middle marker	30 sec later

D1167.03

Full-Mission Simulation

Workload Levels

Conditions	Level		
	High (LAX → SFO → OAK → SMF)	Low (SFO → SCK)	Incapacitation (SMF → SFO)
Weather	LAX: Ceiling 500 ft; visibility, 3 mi OAK: Ceiling 200 ft; RVR zero SMF: Clear, visibility 15 mi	Clear	Clear
Wind	LAX: Calm OAK: Calm SMF: 340 at 10 kn	Calm	Calm
Non-normals	• "A" system hydraulic low pressure light illuminated • Number three engine flameout • Hydraulic system "A" failure	None	F/O Incapacitation

D1167.08

Operationally Relevant Types of Workload

FAR 25.1523, Appendix D

- FAA addresses
  - 6 workload functions
  - 10 workload factors
- Map FAR-25 function and factor descriptions into scenarios
- Divide scenarios into high and low workload levels based on objective task demands

A1167.06

Basic Workload Functions
FAR-25

1. Flightpath control
2. Collision avoidance
3. Navigation
4. Communications
5. Operations and monitoring of aircraft engines and systems
6. Command decisions

A1167.07

Workload Factors

FAR-25

1. Controls
2. Displays
3. Procedures
4. Mental and physical effort
5. Monitoring
8. Communication and navigation

9. Nonnormals
6. Crew member out of area
7. Automation breakdown
10. Incapacitated crew member

A1167.08

Function and Factor Mapping

Example

00:02:15		Gear Retract - Start Initial Climb
Function	**Factor**	
4,5,6	3,8A	• Calls, "gear up"
4	8A	• Hears F/O, "gear up"
5	5	• Sees F/O compliance (peripheral vision)
1,5	2,3,5	• Looks to see if airspeed stabilized at approximately V2 + 10
1,5,6	1,2,3	• Adjusts pitch attitude to maintain V2 + 10 if necessary
1,5,6	1,2,3	• Sets FD pitch knob to proper pitch attitude
00:02:35		Cleared Direct Sacramento Vortac

A1167.09

Dependent Measures

- Subjective
- Physiological
- Performance
- Task timeline analysis

A1167.11

Dependent Measures

- Subjective
  - NASA TLX
  - SWAT
- Physiological
  - Heart rate variability
  - Eye blinks
  - Eye movement
- Performance
  - Primary task
  - Secondary task
- Analytical
  - Task timeline analysis

A1167.32

Subjective Measures

- Subjective workload assessment technique (SWAT)
- Task load index (TLX)
- Overall workload score (simple 20-point scale)

B1123.04

Subjective Measures

- Inflight (direct measurement)
- Postflight (videotape)

- Example measures
  - NASA TLX
  - SWAT

A1167.12

Physiological Measures

- Eyeblink rate
- Eye movement
- Heart
  - Rate
  - Rate variability
- Heart spectral analysis
  - Blood pressure component
  - Respiration component

B1123.05

Performance Measures

- Primary Task
  - Reversals
    - Stick
    - Rudder
    - Aileron
    - Throttle
  - Approach and landing
    - Flightpath error
    - Glideslope and localizer variability
    - Altitude at outer, middle, and inner markers
- Secondary Task
  - Sternberg RT task

A1167.14

Secondary Task

- Two "flight numbers" are designated positive probes
  - Pilot's own flight number (United 247)
  - Another aircraft flight number (United 241)
- Pilot is instructed to respond as quickly and accurately as possible
- Pilot response is to toggle "push to talk" switch

B1123.06

Secondary Task Measures

- Response time
- Probe accuracy

B1123.07

Task Timeline Analysis (TLA)

- Selected segments
- Proven TLA method
- Identifies high and low task-demand levels
- Validity of workload measures against proven tool

A1167.15

Full-Mission Simulation

Experimental Design

Experimental Order

1	2	3
SMF-SFO SFO-SCK LAX-SMF	SMF-SFO LAX-SMF SFO-SCK	SFO-SCK SMF-SFO LAX-SMF
1,7,13,22	4,10,16,19	2,8,14,23

4	5	6
SFO-SCK LAX-SMF SMF-SFO	LAX-SMF SFO-SCK SMF-SFO	LAX-SMF SMF-SFO SFO-SCK
5,11,17,20	3,9,15,24	6,12,18,21

D1167.18

DISCUSSION
SUMMARY POINTS

IMPLEMENTATION OF A UNIDIMENSIONAL WORKLOAD MEASURE:

The feasibility of using a unidimensional workload scale, in addition to the other subjective measures taken, was discussed. The possibility of using a "Modified Cooper-Harper" or the "Bedford Scale " was addressed. The Bedford Scale is a measure of spare capacity. Some felt the pilots have trouble assessing their "spare capacity". The Bedford Scale is used extensively in the European community, and the FAA showed a great interest in having it assessed during full-mission testing. The Bedford Scale would be administered post-flight with the use of video tapes.

IN-FLIGHT RATING ISSUE:

Should the use of in-flight ratings be incorporated in full-mission simulation? A number of suggestions were made to include an in-flight subjective measure to provide opportunity for a comparison of in-flight versus post-flight subjective assessment. The discussion included the question of which rating scale could be employed in the particular scenarios already built for full-mission testing. SWAT scores can be taken verbally and will work in the given scenarios. The workload involved in these scenarios precludes the use of a "clipboard" by the pilot to give his ratings. Correct administration of NASA's TLX requires a "clipboard" approach. The question of when these ratings would be taken in-flight was also raised. If the ratings are requested at the end of the measurement windows, then pilots may learn where the measurements are being taken. This needs to be avoided as the pilot might change his performance (i.e., try harder or be better) at specific times because he knows he is being measured . It was suggested that measurements be taken at variable intervals, both during and outside of measurement windows. A final point was made that if, in fact, SWAT ratings are taken "at the moment" of the window closing then the scores given may reflect only the workload at that particular moment and not the workload of the whole measurement period (i.e., the measurement window).

SECONDARY-TASK ADMINISTRATION:

The problems that occurred with application of the secondary-task measure during the part-task simulation were discussed. The switch used by the pilot to respond to the positive probes blanked ATC with the switch closure. The feasibility of using a different switch was discussed. A suggestion was made to use verbal responses. It was concluded that voice relay is not a feasible alternative in the noisy cockpit environment. The noises often trigger the switch relay, and the variability using this technique is extremely high. The design of the secondary task was discussed in length. Many felt the secondary task technique couldn't be used in the flight test portion of certification. It was determined, however, that the secondary task may be valuable even if it can only be used in simulation. Even though it was handicapped during the part-task testing by problems that were encountered, it's data showed great promise. The problems that occurred in part-task can be controlled in full-mission testing. Several other types of tasks were suggested for use as a secondary task measure; however, they lacked the requirements of the secondary task to have both positive and negative probes and to have the probes occur often enough to gather a good base of data. Since data is collected on the Captain only, the task must also be one that is normally performed by the Captain. The Boeing and Douglas team members working this contract are currently evaluating all alternatives.

USE OF AUTOPILOT ISSUE:

Autopilot implementation during part-task simulation was discussed. In part-task testing, the use of autopilot was left to the pilot's discretion, and thus, its use became inconsistent across the subject population. It was felt that a tighter control on the use of autopilot (or preventing its use altogether) in full mission testing should be required. Various ways to accomplish this were discussed, such as incorporating additional autopilot training into differences training or using the confederates in the cockpit to aid in consistency of use. It was suggested that if the autopilot could be an MEL item for all legs, there would be no chance of inconsistency among subjects. It was agreed that for full-mission testing the autopilot would be MEL for all legs.

INCAPACITATION ISSUE:

It was submitted that during full-mission simulation testing the first officer might be incapacitated during one leg of the scenario. The question was raised whether the first-officer is being incapacitated in order to study the "incapacitation" issue or to manipulate the Captain's communications workload. A discussion on which approach is more relevant for certification ensued. If the question is, in fact, "can the measures detect changes in increased communications (e.g., radio communications)?" then an "incapacitation" scenario may not be the best alternative. An incapacitation introduces a large and complex set of task demands. It may be better, in fact, to introduce a specific set of task demands (e.g., radio communications) to be the Captain's assigned task in addition to his normal duties. This discussion included the considerations that must be made for all phases of certification. For instance, if an incapacitation scenario is used, where does incapacitation of the first officer occur (i.e., in what phase of flight), how are the airline procedural differences in handling an incapacitation accounted for, and when incapacitated, is the first officer removed from his seat? Both issues, incapacitation and communications workload, cover workload factors of FAR 25, Appendix D, which were not manipulated in the part-task study. The Boeing/Douglas team working this contract is evaluating all possibilities.

WRITTEN COMMENTS PROVIDED BY ATTENDEES

WORKSHOP #2

FULL-MISSION SIMULATION SUGGESTIONS

1. For incapacitation you could try the following:

   A. Captain says "I have briefed flight attendants, the F/O is being cared for by a physician, ATC has been advised, EMS is standing by, you will be vectored with priority. Also, company has been advised."

   B. Have Preston suggest, "You look tied, why don't you use the autopilot?" As a means of standardizing autopilot use.

   C. Keep your high workload profile as it is. I believe it will measure sensitivity at high levels.

2. Use simple scale (say Bedford or Airbus) during flight.

3. Do TLX post flight.

4. Drop SWAT on the assumption that it correlates well with TLX.

5. Draw the pilots from a:
   -single carrier
   -2 carriers and balanced
   -3 carriers and balanced.

6. Certification would take the autopilot being an MEL item on all flights.

7. SWAT did well on high workload, so do a regression TLA-SWAT check correlation. Use weights for the next simulation.

8. In your study, you used visibility and wind conditions to manipulate workload levels. However, as I understand it, TLA does not take these conditions into account. Consequently, how can you use TLA as your baseline metric?

9. It seems that a lot of confounds occurred due to pilot training in dealing with anomalous situations. Some pilots dealt with emergencies singlehandedly whereas others delegated tasks to other crewmembers. Consequently, your data represented different types as well as levels of workload. During full mission simulation, you may want to impose stringent operation procedures in order to control for some of these confounds.

10. It makes sense that workload should be consistent as possible within bounds of "normal" operations. It does not make sense to try to combine workload measures for pilots who use autopilot and those who do not.

11. Since (a) you have a small "N" and (b) dispatch with autopilot inoperable is accepted by the MEL, why not use a "failed" autopilot in your tests.

12. I recommend that your experimental procedures be reviewed to maximize the degree of task and task load commonality within the bounds of "normal" operations.

13. If a secondary task is used, why not consider realism of task demand as one of the criteria? This may not be feasible for available secondary task list, but the concept deserves consideration.

14. You have a two crew- three crew source of confusion between earlier and present test plans. Accordingly, even though you plan emphasis on a two crew operation in coming tests, why not start the flight with three than "disable" one. This would establish a connecting link between the two series of tests as a meaningful basis for comparison across tests.

15. Did the analytical (TLA) approach include the variations in degraded modes of operation? If not, a higher degree of correlation might be found between analytic and empirical results.

16. Discussions indicate you are considering changing applications of tools (e.g., SWAT may be used in flight when it was earlier used post flight). When the conditions of application are not the same, there is a high likelihood that subtle differences in results will occur. Context dependency cannot be ruled out, as thousands of graduate students found out in studies of semantic differential. Also, there is a strong possibility the "inflight" ratings, will be remembered to some degree and have an influence on "post flight" ratings.

17. I am concerned that we are measuring (or attempting to measure) pilots reaction to changes that affect the tasks he must perform. We choose to call this reaction "workload". The experimental design you have chosen, changes the tasks the crew must perform, as a funtion of the scenario and introduction of malfunctions. What it appears you wish to address is changes in configuration (from a base line aircraft "A" to a new configuration "B"), and those affects, reaction of the task, workload. Also you may want to address changes in crew size, crew training, procedures, environment, etc.

    My concern is the level of reaction that we measure as a result of malfunctions introduction into a mission, may have very little, if any, correlation to other changes, such as crew station configuration, crew size, etc. Research must be conducted to determine if the measure that is sensitive to one change is still a reliable measure for other changes that affect crew tasks and are seen in measurable, significant change in workload.

18. The point that was made in regard to the coarseness of the sensitivity of the parameters to detect workload is well taken. Simply because the parameters chosen can distinguish increases in workload during anomalous conditions, it does not follow that they can detect subtle changes in workload. Granted, one must investigate the capability to detect coarse events initially, but you need to go one step further in your full mission simulation. For example, introducing poorly designed display formats which are known to increase workload might be an approach to further defining the sensitivity level of the parameters that have been chosen.

USAF/FAA REVIEW OF WORKLOAD MEASUREMENT METHODS: PART-TASK SIMULATION DATA SUMMARY WORKSHOP

WORKSHOP #2 PROCEEDINGS DISTRIBUTION LIST

Donald Armstrong
Federal Aviation Administration
4344 Donald Douglas Drive
Long Beach, CA 90808

Dr. Randall B. Aust
McDonnell Douglas Helicopter Co.
Building 531, C240
5000 East Mc Dowell Road
Mesa, AZ 85205

Dr. Frank Austin
FAA ASF-4
800 Independence Avenue SW
Washington DC 20591

Dr. R. M. Barnes
CAA House Civil Aviation Authority
45-49 Kingsway
London, WC2B 6TE England

Robert P. Bateman
Boeing Military Aircraft Co
P.O. Box 7730
MS K80-19
Wichita, KA 67277-7730

Mr. V. Battiste
NASA Ames Research Center
Attn: MS-239-3
Moffet Field, CA 94035

Herb Berry
M.C. 75-11
Douglas Aircraft Company
3855 Lakewood Blvd.
Long Beach, CA 90846

Dr. Michael A. Biferno
McDonnell Douglas Corporation
E21 MC 209-01
3855 Lakewood Blvd.
Long Beach, CA 90846-0001

Dr. Alvah C. Bittner
Analytics
2500 Maryland Rd.
Willow Grove, PA 19090

Dr. Richard Blomberg
Dunlap and Associate East Inc.
17 Washington Street
Norwalk, CT 06854

Michael R. Bortolussi
NASA Ames Research Center
Attn: MS-239-3
Moffet Field, CA 94035

George Boucek
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Sqn. Ldr. Harry Britten-Austin
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Capt. Robert G. Buley
Check Airman - Flight Training
M/S G-7200
Northwest Airlines Inc.
7500 Airline Drive
Minneapolis, MN 55450

Larry C. Butterbaugh
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Kim Cardosi
DOT/TSC
DTS-45
Kendall Square
Cambridge, MA 02142

Robert E. Chaney
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 6L-38
Seattle, WA 98124-2207

Rob Chatfield
Federal Aviation Administration
Flight Standards Division, ANM 270S
17900 Pacific Highway S.
C-68966
Seattle, WA 98168

Dr. Richard E. Christ
ARI Field Unit
P.O. Box 6067
Ft. Bliss, Texas 79906

Philip Condit
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 75-26
Seattle, WA 98124-2207

Dr. C. W. (Bill) Connor
Delta Air Lines, Inc.
1722 Ponce De Leon Blvd.
Coral Gables, Florida 33134

Dr. William Corwin
McDonnell Douglas Co.
MC 209-01
3588 Lakewood Blvd.
Long Beach, CA 90846-0001

Dr. William L. Derrick
AF/DPXA
The Pentagon Room 5C360
Washington D.C. 20330-5060

Dr. Alan Diehl
HQ AF 16C/SER
Norton AFB, CA 92409-7001

Michael Dresel
Boeing Military Aircraft Co.
P. O. Box 7730
MS K78-08
Wichita, KA 67277-7730

Dr. F. Thomas Eggemeier
Department of Psychology
University of Dayton
300 College Park
Dayton, OH 45469

Chet L. Ekstrand
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 2T-62
Seattle, WA 98124-2207

Mr. Terry Emerson
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Kennith Erdman
FAA ASF-4
4344 Donald Douglas Dr.
Long Beach, CA 90808

Delmar Fadden
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 01-81
Seattle, WA 98124-2207

Dr. A. D. Fisk
160 Minehead Road
Irmo, South Carolina 29063

Dr. J. P Fouillot
Laboratoire de Physiologie
Faclute de Medicine Cochin
24 Rue du Faubourg St. Jacques
Paris 75014 France

Dr. Richard F. Gabriel
McDonell Douglas Co.
Dept E21 MC 209-01
3855 Lakewood Blvd.
Long Beach, CA 90846-0001

Charles W. Geer
Boeing Aerospace Company
P. O. Box 3999
MS 8K-03
Seattle, WA 98124-2499

Daniel Gopher
Technion-IIT
Faculty of Industrial Eng. & Mgt.
Haifa 32000 Israel

Berk Greene
FAA ANM-160S
17900 Pacific Highway South
C-68966
Seattle, WA 98168

Peter Hancock
University of Southern California
Dept. of Safety Sciences
Los Angeles, CA 90089-0021

Dr. Randell Harris Jr.
NASA Langley Research Center
MS 152E
Hampton, VA 23665

Wolf Hebenstreit
Boeing Aerospace Company
P.O. Box 3999
MS 2K-58
Seattle, WA 98124-2499

Capt. Mel Hoagland, Jr.
261 Columbine Lane
Evergreen, CO 80439

Jack Howell
934 SW 2nd Street
Boca Raton, FL 33432

Dr. Peter V. Hwoschinsky
FAA APM-430
800 Independence Avenue SW
Washington D.C. 20591

Dr. Richard S. Jensen
Ohio State University
Dept. of Aviation
Box 3022
Columbus, OH 43210

Jon Jonsson
Douglas Aircraft Company
Mail Code 209-1
3855 Lakewood Blvd.
Long Beach, CA 90846

H. H. Knickerbocker
M.C. 41-58
McDonell Douglas Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

Dr. Arthur F. Kramer
University of Illinois
Psychology Department
603 East Daniel Street
Champaign, IL 61820

Capt. Thomas J. Kreamer
1205 Croton Drive
Alexandria, VA 22308

Capt. Roland B. Liddell
P.O. Box 584
Corte Maderra, CA 94925

Aileen Logan
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Gary Lopez
Federal Aviation Administration
New England Region, ANE-265
12 New England Executive Park
Burlington, MA 01803

George Lyddane
ANM-104N
16005 Sabanahane
Encino, CA 91436

Joseph MacDonald
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 26-09
Seattle, WA 98124-2207

Teresa L. Mann
Lockheed Georgia Co.
Marietta, Georgia 30063

Capt. Alvah S. Mattox Jr.
12723 Brewster Circle
Woodbridge, VA 22192

Lt. Kim Mazur
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. Thomas M. McCloy
United States Air Force Academy
Behavorial Science & Leadership Dept.
Colorado Springs, CO 80840

Dr. James McGuire
M.C. 35-36
McDonnel Douglas Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

Dean Melton
FAA ANMN-160S
17900 Pacific Highway South
C-68966
Seattle, WA 98168

Dr. Henry W. Mertens
Human Performance Research Unit
FAA/CAMI
Box 25082 AAC-118
Oklahoma City, OK 73125

Dr. Sam Metalis
McDonnell Douglas Co.
E21 MC 35-36
3855 Lakewood Blvd.
Long Beach, CA 90846

Thomas R. Metzler
U.S. Army Research Institute
AVSCOM PERI-IRA
4300 Goodfellow Boulevard
St. Louis, MO 63120-1798

Dr. Neville Moray
University of Illinois
Department of Industrial Engineering
Urbana, IL 61801

Daniel Mottard
DGAC-SFACT
364 Rue DuLouvre
75001 Paris, France

Dr. Susan Norman
Chief Aeronautical Human Factors
Research Officer
NASA-Ames Research Center
Moffett Field, CA 94035

Dr. Robert D. O`Donnell
NTI Corporation
4130 Linden Drive, Suite 235
Claypool Building
Dayton, OH 45432

Capt. J. G. Oliver Jr.
5097 Riverview Rd., NW
Atlanta, GA 30327

Harry W. Orlady
Battelle ASRS Office
625 Ellis Street, Suite 305
Mountain View, CA 94043

Dr. Charles Overbey
Operational Test & Evaluation Division
FAA AST-200
800 Independence Ave., SW
Washington D.C. 20591

Don L. Parks
Boeing Military Airplane Co.
P.O. Box 3707
MS 33-22
Seattle, WA 98124-2207

Robt. Paty
Chairman Safety Committee
APA
P.O. Box 5524
Arlington, TX 76005

Thomas Penland
FAA AFS-250
800 Independence Avenue SW
Washington DC, 20591

Dr. Evan Pickrel
FAA AAM-500
800 Independence Avenue SW
Washington, DC 20591

James Plakis
FAA New England Region
New York Aircraft Certification Offce, ANE 170
181 S. Franklin Ave.
Valley Stream, NY 11581

Gary B. Reid
USAF/AMRL
Wright-Patterson Air Force Base
Dayton, OH 45433

George Reid
Boeing Aerospace Company
P. O. Box 3999
MS 8K-03
Seattle, WA 98124-2499

Dr. John M. Reising
AFWAL/FIGR
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. Alan Roscoe
Britannia Airways Ltd.
Luton Airport
Bedfordshire LU2 9ND United Kingdom

Bill Russell
Air Transport Association
1709 New York Avenue NW
Washington, DC 20006

John Rye
Civil Aviation Authority
CAA House
45-59 Kingsway
London WC2B GTE United Kingdom

Diane L. Sandry-Garza
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

Dr. Richard Schiffler
ASD/ENEC
Wright-Patterson Air Force Base
Dayton, OH 45433

Dr. Samuel B. Schiflett
USAF SAM/VNB
Crew Technology Division
Brooks AFB, TX 78235

Dr. William Shepherd
FAA AAM-550
800 Independence Avenue SW
Washington, DC 20591

Dr. Clark A. Shingledecker
NTI Inc.
Suite 235
4130 Linden Avenue
Dayton, OH 45432

Robert J. Shivley
NASA Ames Research Center
MS 239-3
Moffet Field, CA 94035

Eric Shreder
M.C. 35-65
McDonnell Douglas Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

Kim Siler
Lockheed-California Co.
P.O. Box 551
Burbank, CA 91520

Troy D. Sims
FAA - Aircraft Evaluation Group
601 East 12th Street
Kansas City, MO 64106

Dr. Don Smith
7310 Valburn Drive
Austin, TX 78731

Jean-Jacques Speyer
Airbus Industrie
Performance & Operations Engin.
Flight Division HQ BP No. 33
31707 Blagnac Cedex, France

Dr. John A. Stern
Professor Psychology
Washington University Box 1125
St. Louis, MO 63130

Frank Stogsdill
Federal Aviation Administration
601 E. 12th Street
Kansas City, MO 64106

Harty G. Stoll
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 77-35
Seattle, WA 98124-2207

Jerry Stone
M.C. 202-12
McDonnell Douglas Co.
3855 Lakewood Blvd.
Long Beach, CA 90846

Preston Sult
Boeing Commercial Airplane Co.
Post Office Box 3707
MS 2T-61
Seattle, WA 98124-2207

Guice Tinsley
FAA AFS 210
890 Independence AVE., SW
Washington D.C. 20591

David M. Trousdale
331 Cochran Drive NW
Atlanta, GA 30327

Capt. Frank Tullo
Program Manager
Cockpit Resources Management
Continental Airlines Inc.
7300 World Way West
Los Angeles, CA 90009-2044

Dr. Joseph P. Tymczyszyn
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 66-25
Seattle, WA 98124-2207

James E. Veitengruber
Boeing Commercial Airplane Co.
P.O. Box 3707
MS 06-14
Seattle, WA 98124-2207

W.A. Wainwright
BAE Civil Division
Hatfield
Hertfordshire AL10 9TL England

Larry Walrath
McDonnell Douglas Company
Building 107 MS 10
P.O. Box 516
St. Louis, MO 63166

Dr. Christopher D. Wickens
University of Illinois
Department of Psychology
603 East Daniel Street
Champaign, IL 61820

Antoinette R. Williams
NASA Ames Research Center
Bldg. 257-1
Moffet Field, CA 94035

Dr. Ken Williams
McDonnell Douglas Co.
E21 MC 35-36
3855 Lakewood Blvd.
Long Beach, CA 90846

Dr. Glenn F. Wilson
USAF
AMRL, AAMRL/HEG
Wright-Patterson Air Force Base
Dayton, OH 45433-6573

Brien Wygle
Boeing Commercial Airplane Co
P.O. Box 3707
MS 24-10
Seattle, WA 98124-2207

Angelos Xidias
FAA ANM-111
17900 Pacific Highway South
C-68966
Seattle, WA 98168