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THESIS

SOUND-SLIDE PROGRAMMED LEARNING

by

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Sound-Slide Programmed Learning

by

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ABSTRACT

In an attempt to improve upon the traditional "lecture and textbook" mode of teaching, an Audio-Visual Response Teaching Machine was utilized for certain topics in gasdynamics. This teaching system was based on three elements: programmed instruction, a Question/Response/Answer technique, and continuous confirmation of answers. The teaching machine is a portable self contained unit consisting of a dual track cassette tape recorder, viewing screen, slide magazines, remote control, and a Respondex keyboard. Detailed scripts (including multiple-choice questions) were written, slides were prepared and synchronized audio-visual programmed lessons were assembled. The results are two individual packages on Reaction Propulsion Systems: The Brayton Cycle and Thrust, Power and Efficiency. Student reaction to these programs was favorable. It was concluded that this method should be used in a supplemental capacity to the course and recommended that work in this field continue.

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I. BASIC PRINCIPLES OF PROGRAMMED INSTRUCTION

What method of teaching should be used so that maximum comprehension and retention are obtained? Traditionally, the lecture and textbook mode has been the means of conveying the desired information to the student. Some other current methods of instruction include:

Programmed Texts

Computer Assisted Instruction

Self Paced Instruction

Audio-Visual Techniques

Each method has its own merits and limitations and is probably an optimal system under certain circumstances. In each of these systems the student learns more by taking an active role in the learning process, and at the same time the instructor is freed from repetitious lectures so that he might become more productive in other areas.

An ideal system of instruction should include three elements which derive from the results of educational experiments and studies conducted in the 1960's. The first element is programmed instruction; the second element is a Question/Response/Answer technique (the Socratic method) of imparting information as opposed to Statements of that same information; and the third element consists of continuous confirmation of a student's successful answers.

A. PROGRAMMED INSTRUCTION

Most people think of programmed instruction as the programmed text, but this is a very restricted viewpoint. Perhaps a better term would be "programmed learning" but it might be some time before this expression receives widespread use. Programmed instruction is any learning system in which a concise, logical development is designed to lead the student step by step from what he knows to the stated performance objectives of the program [Wales 1969]. Because the flow of concepts follows this pattern, the interesting but extraneous material found in the typical text is usually eliminated. Research data [McKeachie 1968] indicate that this is a desirable omission because "...beyond a certain point adding to the elements in an intellectual task causes confusion and inefficiency."

Thus, the focus usually found in programmed learning is an important characteristic that aids the new learner. As he studies a program, the student actually participates in a guided discovery experience in which new concepts are developed and applied. The student is not a passive reader; he is a participant.

By its Socratic form, the program provides the student with many of the best features of fine tutorial instruction. The program shapes the student's understanding by establishing simple behaviors which are gradually combined and modified until they lead to the performance objectives established for that program. The linear style of programming

provides the most direct control of this shaping process. In addition, it makes the student a more active learner because it incorporates many questions, and to answer each question the student must reformulate the given information in terms of his own vocabulary, background, and structure of ideas. Psychologists believe these to be extremely important acts in the learning process.

Is a programmed text really more effective than a conventional text in transmitting information to the student? The psychologist Ausubel says it is [Ausubel 1963]. He describes the usual text as logically sound but psychologically incongrous in that concepts are segregated by topic, the relationship between concepts is often not clarified or is lost in a maze of detail, and material is developed at a uniformly high level of abstraction that better suits the ability of someone who is familiar with the concepts - not a new learner. By contrast, Ausubel describes optimal programmed instruction as a system which develops concepts in a logical sequence from the simple to the complex. In this way the program builds the hierarchical structure that matches the way in which psychologists believe knowledge is organized and stored by human beings.

B. QUESTION, RESPONSE, ANSWER TECHNIQUE

Suppose one had read an article about the tourist attractions in Paris and it was desired that he learn the height of the Eiffel Tower. Then the question - "How high is the Eiffel Tower?" - pause for the student response - then the

correct answer - "984 feet" - provides the same information as the statement - "The Eiffel Tower is 984 feet high." Is something "extra" achieved by the Question/Response/Answer technique over and above the statement method of imparting information? To answer this, and other questions, concerning this unusual technique Sime and Boyce conducted extensive experimentation [Sime and Boyce 1969].

Their first objective was to demonstrate whether or not any extra teaching benefit results from the Q/R/A technique. This experiment accounted for any effect on learning due simply to imparting of information, by using a control group which was exposed to statements giving equivalent information to the questions and answers seen by the experimental group. A measured difference in favor of the experimental group would therefore reflect the "something extra" in which they were interested.

The second objective was to examine any such effect in relation to two separate hypotheses, each of which would predict superior performance from the use of the Q/R/A technique.

1. Responses which are reinforced by immediate confirmation will be better learned.

2. Constant expectation of a question will heighten attention to the teaching materials and thus facilitate learning.

The experimental procedure consisted of a 30-minute tape recorded lecture coupled with an overhead projector shown to 78 college freshmen. Half of the students saw multi-choice question transparencies periodically throughout the

lecture. They answered by means of a "response box" which was monitored at a central console. If correct, a green light appeared on the response box; if incorrect, a red light appeared.

Perhaps the most important point the experiment showed was that, overall, the "Questions Group" learned more than the "Statements Group". The difference was not large, but asking a question and providing the student with an evaluation of his response does, apparently, provide "something extra" over and above the direct imparting of information contained in the question plus answer. The experiment attempted to discriminate between two hypotheses which could account for this effect, one in terms of reinforcement, the other as a generalized heightening of attention. Based on the results, the authors lean towards a qualified support for the attention hypothesis.

C. CONTINUOUS REINFORCEMENT

Element three deals with the degree of confirmation of answers to questions. Should every answer be given, thus constituting total reinforcement, or should partial reinforcement be utilized in order to yield more effective learning?

In order to determine the effect of partial reinforcement in programmed instruction, three sample groups of 14 year-old children studied a 140-framed program [Berglund 1969]. Each sample group was exposed to a different degree of reinforcement concerning the answers to the questions in the

program. The three sample groups were as follows:

1. Continuous confirmation: the confirming answer was given for every response.

2. Fixed-ratio 50% confirmation: the confirming answer was given for every second frame in the sequence.

3. Fixed-ratio 25% confirmation: the confirming answer was given only for every fourth frame in the sequence.

A criterion test was given the day following the completion of the program and the same test was administered one month later.

In order to eliminate the possible effects of ability on the criterion test, a test battery was administered. The battery contained four different ability tests, verbal, spatial, numerical, and a reasoning test. Before beginning the actual experiment, the four ability tests were administered.

The subjects were given sufficient time to complete the 140-frame program. As soon as a subject had completed all 140 frames, the teacher recorded the amount of time the subject had spent on the program. In addition, the subjects answered a question about the difficulty of the program. The subjects were not told that they would be tested on the material in the program. The criterion tests were administered as mentioned above. The fixed-ratio 50% reinforcement tended to give the highest and fixed-ratio 25% reinforcement tended to give the lowest performance on the immediate criterion test, but the differences among the conditions did not approach a conventional level of significance.

The results of the delayed criterion test showed a perfect rank order relationship between degree of reinforcement and criterion test performance. The differences among the groups were, however, insignificant. The differences among the experimental conditions on the delayed criterion test were insignificant and less than the differences among the conditions on the immediate test. This is a result often obtained in programming experiments; differential effects among conditions in immediate performance do not last over periods of time. The degree of reinforcement and the time spent on the program are negatively related. Since the experimental groups differ significantly with respect to time spent on the program but not with respect to performance, the conclusion drawn is that reinforcement affects learning time and performance independently.

Reviewing, the three elements which are considered essential to promote good learning are:

1. Programmed Instruction; a direct and concise guided discovery experience.

2. Q/R/A technique; Q/R/A students learn more than "Statement" students.

3. Continuous reinforcement; learning time is decreased.

II. REVIEW OF SOME AUDIO-VISUAL TEACHING PROGRAMS

Many applications of audio and/or visual teaching techniques are currently in use at various colleges in the United States. The apparatus might consist of slides, cassettes, television, appropriate visual materials or combinations of these. Some of these programs are discussed below.

A. The first area of audio-visual education to be examined is a particularly intriguing one. The audio tape cassette is the key component of this system. Interactive lectures are being used at Boston University [Miller 1973]. This system creates a situation wherein a student can learn content by listening to a lecture, but also can ask questions and readily obtain appropriate and relevant answers. To use an interactive lecture, a student first listens to the basic recorded presentation, stopping the tape at any time that a question comes to mind. A "map" associated with the presentations lists questions that students have asked previously and identifies the location of the answers on additional cassettes. The student can run an answer cassette to the indicated position, listen to the answer, and then proceed with the basic presentation or pursue other questions, as desired.

In addition to permitting a wide range of student questions, the interactive lecture is ideally suited to individualized study use. Experience has shown that a carefully

edited, taped lecture can present content in one half to one third the time most lectures would use in the classroom.

B. Another way in which audio cassettes are used is in problem-set tapes. Many engineering courses involve the extensive use of problems as a means to encourage students to master the concepts. Problem sets are frequently assigned, but the task of correcting them and assisting each student to understand his mistakes is such a time-consuming effort that it is not always carefully done on a regular basis. As an alternate approach to the problem, some professors distribute written answer sheets. An extension of the practice of using answer sheets consists of a package combining an audio tape commentary and the written answers. These particular cassettes record authors' comments on problems from their books; but any teacher can prepare similar tapes for any text if they so desire. Most students prefer brief treatments with an emphasis on the difficult or unusual aspects of the problem, presented in a journalistic fashion: main idea first, details later.

A new device called "Sound Page" (produced by 3-M) permits the problem solution to be visually presented on one side of special paper. The other side contains a recording of up to 4 minutes of commentary concerning the problem situation. A library of these can easily be prepared to cover all problems in any course.

C. A final use of audio tapes is in laboratory situations. The most common application is the familiarization of students

with the use of various test equipment. For example, a number of tapes have been prepared to teach the use of oscilloscopes and signal generators.

Audio-tutorial instruction does have its drawbacks. Students find that just listening is an unsatisfactory experience. With nothing more interesting to engage the eye than the little machine, the eye is easily attracted by any nearby activity or available reading matter and attention wanders from the audio message. To alleviate this problem, the visual sense must be purposely engaged, either in an activity related to the audio message or in a non-distracting activity. Most applications mentioned above include this practice in their design. <u>The audio tape should never be used without some visual accompaniment</u>.

D. At the University of Denver, slide packages are used to give detailed instructions on particular laboratory experiments before the associated theory is presented; this procedure is entitled "Teaching Through Hardware" [Seshadri 1972] Self-learning takes place at the hardware stage, when students use 35mm slides which enables them to manipulate the piece of hardware in question. The hardware can be any number of laboratory devices, or even bits of wood or lumps of metal.

Each program consists of between 50 and 2000 slides, depending upon the complexity of the subject matter in question. The slides are divided into three parts, including Information, Instruction, and Demonstration slides.

Information slides supply specific, unclouded and well-timed information in order to develop terminology and prepare the student's mind for some action. Instruction slides provide the sequence of events necessary for the manipulation of the hardware and its related equipment, and finally the production of a tangible result. This tangible result may be in the form of a graph, a photomicrograph, a table of values, figures, calculations, figures from chemical analysis, a hand sketch, a drawing, a finished workpiece, a written report or conclusions based on their learning experience. Demonstration slides show action, including what might and should happen, and what could go wrong during an operation or manipulation.

The conclusions drawn are:

1. Students who are exposed to this teaching technique are capable of gaining their own learning experience. Students' retention is of the order of 75 - 85%.

2. This teaching technique also exposes the hidden capabilities of some students who believe that they are total educational write-offs.

3. Student learning time is greatly reduced.

E. In the Department of Aeronautics at the Naval Postgraduate School, Slide-Tape briefings for low speed wind tunnel laboratories are currently in use. These Slide-Tape packages have automatic programming to give fully synchronized audio-visual briefings which can be used for individual or group lectures [Palka and Wallace 1973].

The programs include sections on various methods by which the desired information can be obtained (together

with the advantages and disadvantages of each), installation procedures, type of instrumentation used, operation of the equipment, and in some cases data reduction techniques.

When sufficient programs have been prepared, the lab can be run on a "do it yourself basis" with small groups of students running the equipment any time during the week.

F. In an introductory Fortran programming course at Virginia Polytechnic Institute, an experimental effort was initiated making use of Sound-on-Slide equipment which is produced by 3-M [Beyer and Hackler 1971]. A 4" x 4" carrier accommodates a 35mm slide and also contains a magnetic disc on which a 30-second message can be recorded. Up to 36 carriers can be placed in one tray for projection.

The strategy for the utilization of this system in class is somewhat similar to that of programmed instruction. A series of slides with the accompanying audio material is presented. At the end of a brief presentation (5-8 minutes) the machine is turned off and a problem assigned to be worked immediately. In some cases it is appropriate to have some of the information from the slides reproduced as a handout for reference. After a period of time the next slide and text presents a solution to the problem, so immediate reinforcement is present. It has been found that this "interruptable presentation" is a good teaching method.

A most delightful feature of this system is the fact that revisions come easy, since revisions are made frame by frame. Slide carriers can be interchanged if a change in

the order of presentation is desired. Additional slides (and the accompanying audio message) can be inserted, or a message can be erased and then recorded again. Furthermore, the presentation can be "backed up" and restarted <u>at any point</u> and the sound is always synchronized with the picture.

Relative to performance of students in experimental sections as compared with other sections, there were no significant differences. It is firmly believed that a point seldom considered is the time required by the student to learn the assigned material. If learning can be made more pleasant while requiring less of the student's time to accomplish the assigned task, then a substantial improvement has been made. It is Beyer and Hackler's opinion that both of these have been accomplished in this experimental endeavor.

G. The Department of Electrical Engineering at Pennsylvania State University has produced a multi-media presentation for its initial contact with the students in a freshmen engineering orientation [Delansky 1972]. The program runs 10.5 minutes and utilizes 3 carousel projectors, each with 140 slides, a dual-channel tape player, and a control system. One channel of the tape is used for the audio narration and background music while the other channel is used for signals that the control system will use to independently change slides on each carousel. Events happen at quite a rapid rate with each carousel changing slides about every 5 seconds and thus providing the concept of "supersaturation" so appealing to young people today. Actual audience response

to this has been very enthusiastic, but it is recognized that this programming style is only good for introductory lectures.

H. In an effort to increase flexibility in scheduling students into a materials laboratory, the Chemical Engineering Department at New Mexico State University has started preparing TV tapes on each of the experiments to be performed [Wilson 1971]. The tape contains sufficient explanation as to the purpose, procedures, and results of the experiment so that the average student can proceed with and complete the experiment with no additional instruction. In addition, there has been a prior discussion of the objectives or concepts involved. Thus the tape supplements the usual laboratory handout and replaces the 15-minute introduction traditionally given before each laboratory section.

Using this system the student can schedule himself into the laboratory at his convenience. If this degree of flexibility is not considered desirable, such a TV tape could be used in the case of those students who have valid reasons for missing regular laboratory sessions.

I. Television can also be successfully used for instruction [DeShazar and Edwards 1973]. Studies have shown that television can be a highly effective means of motivation and communication in the classroom [Educational Facilities Laboratories 1968]. Learning is best accomplished in very small groups (fewer than four people), where more than one human sense is excited. Television is a means of both seeing

and hearing (and therefore learning) at the same time. Television instruction may also demand that a student participate in a learning experience. Two methods of using television are: videotape recordings, and live programs.

Videotaping allows scheduling and timing to meet the teaching need. Telecasting can be done at any time and offers repetitive instruction. No time is required for processing - it is ready for immediate use after recording. Videotaping is a very simple process. However, there are serious pitfalls for the amateur. Taped programs can be boring. On the other hand, the spontaneity of live television gives "human" contact to the students. Commercial or educational television networks are available for such use in the classroom. Disadvantages of live television are that it has much less flexibility in terms of time, performance, and scheduling. Telecasts must be viewed at the time of performance, and errors in performance are not easily corrected.

J. The College of Engineering at the University of Oklahoma has been using audio-visual response teaching machines to teach a course in basic statistics for the past three years [Foote 1973]. The following principles have been found to be applicable to an audio-visual response teaching mode:

(1) Neither humor nor animation appears to contribute to learning.

(2) Attention-gaining clues that are irrelevant to subject matter are probably detrimental.

(3) Rest pauses help.

(4) Viewing angle is important and should be about 30 to 60 degrees below the horizontal.

(5) Color helps. Use people's color preferences for compatibility and color dislikes as occasional visual shock to regain attention.

(6) Noise is a problem only as it affects audio input.

(7) Children have better auditory skills than visual, but adults have visual skills at least as good as auditory skills; hence, at least 50% of information transmitted should be visual.

(8) Perception of information from a screen in terms of the form and shape of symbols must obey the principles of contour, closure, continuity, symmetry, simplicity, unity, size, shape, form, and the complex responses to super-position.

(9) Students learn better when the overall organization of learning is cognizant of their psychological and personality differences. For example, Fry has shown there are two types of learners, one type that likes to control their learning both in rate and order of presentation and another type which likes the rate and order of presentation controlled by someone else. These types can be identified and do significantly better when material is presented according to their psychological preferences.

(10) No one has found out how learning is really affected by various combinations of joint audio and visual presentation. This same study (at Oklahoma) referred to does have much material on audio and visual presentation separately. For example, material with low "meaningfulness" is learned better visually, but material with high meaningfulness is learned better aurally. That is, the serial order of nonsense words like "gojoy" is learned best visually, but the serial order of words like "kitchen" is learned best aurally.

(11) Giving the student performance objectives before the study begins is of tremendous value.

III. DESCRIPTION OF EQUIPMENT

The Coxco SP-120 Sound/Slide system is a portable audio-visual studio. The unit contains a built-in 35mm slide projector and screen plus a dual track cassette tape recorder. Optional equipment includes a Respondex keyboard. See Figure 1.

The heart of the system is the ability to make one's own fully automatic and synchronized audio-visual programs. A microphone is included so that one can record voice on one track of the tape. After the narration for each slide is completed one places a "slide advance pulse" on the sound track of the tape. This signal will automatically advance the projector to the next slide. An additional feature (not found in most machines of this type) is that a "stop pulse" may also be placed on the second track. This will stop the tape to permit additional viewing time. The unit is then restarted by pushing a "restart" button. Slides are mounted in standard cardboard or plastic mounts and are loaded into 36-slide magazines.

This unit has a great degree of flexibility in that one can record the entire narration, rewind the tape and then record the cueing pulses, or one can record both tracks simultaneously. If one desires to change a slide from automatic mode to manual mode, or vice versa, the original pulse can be erased and a new pulse recorded without disturbing

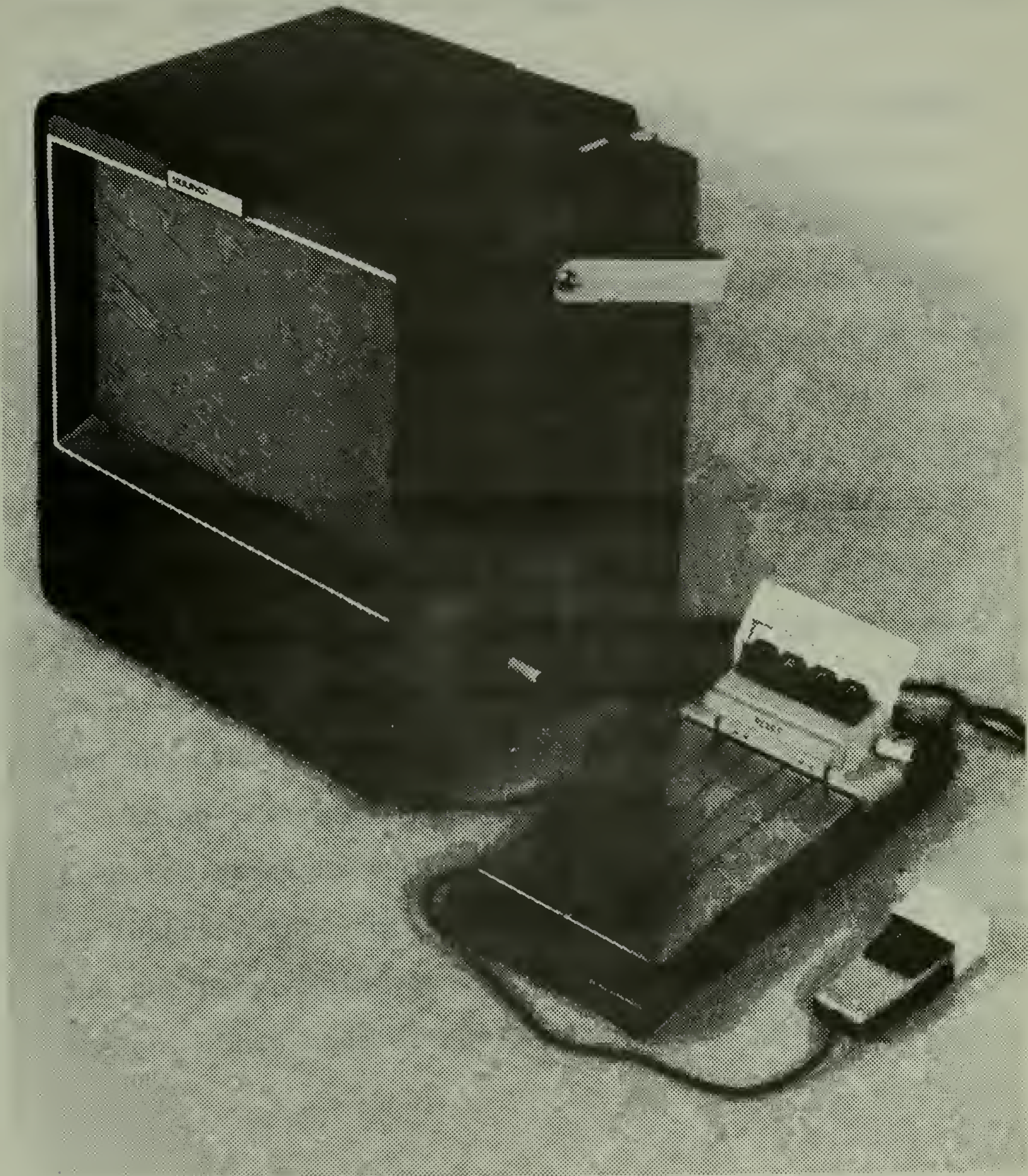

Figure 1. Coxco SP-120 Sound/Slide Unit with Respondex

the audio section, as the two tracks are independent of each other. This feature is not found in all machines of this type.

Active participation of the student can be obtained through the use of the Respondex keyboard which has a capacity of 40 multiple-choice questions with 14 coded answer patterns. When a multiple-choice question slide appears, the tape is programmed to stop. The student makes a choice by depressing the appropriate button on the Respondex keyboard. If the choice is correct, the tape is restarted and the programming continues. The keyboard selector also advances to the next question setting, awaiting the next question slide later in the program. If an incorrect choice is made, the program will not continue and the student must make another choice.

In an alternate mode of operation, the Respondex can be used for straight quizzing. In this mode an IBM punch card is inserted into the keyboard to record the student's answers and the programming continues regardless of the answer chosen. This mode of operation was not used.

IV. GENERAL DESCRIPTION OF PROGRAMS

The overall goal was to produce a three-program sequence in Reaction Propulsion Systems consisting of:

1. The Brayton Cycle
2. Types of Propulsion Engines
3. Thrust, Power, and Efficiency

Unfortunately, time permitted only production of programs 1 and 3.

Formal programmed instruction was modified when it was incorporated with the teaching machine of this project. A moderate amount of information was presented in carefully prepared sequences which develop one or more simple concepts. Then one or more question slides appeared, each with four possible answers. Many people feel that multiple choice questions have no place in higher learning but this belief is considered incorrect. Experiments have shown [Miller and Williams 1973] that there are valid techniques for constructing meaningful multiple-choice questions which require higher level thinking ability. Unfortunately, most of these techniques apply to non-quantitative material and require considerable space to list the choices.

The slides were produced in color in order to make the programs more appealing and to help increase the student's span of attention. Five background colors were used in sequential order whenever possible. However, when a series of slides dealing with one topic was shown, the same background

color was used to emphasize this development. All question slides in a particular program were of the same color.

The construction of the slides was accomplished in three steps. Sketches were made on Vidalon tracing paper using a carbon based ink. Headliner tapes (adhesive-backed tapes with questions or phrases on them) were then applied to the Vidalon. A transparency was then made with either black or white lines by placing the Vidalon in a Thermofax machine. Colored Chart-Pak Tape strips and Zip-a-Tone colors were applied to the transparencies, as appropriate. Finally, these transparencies were photographed on the various color backgrounds by a 35mm camera.

A. THE BRAYTON CYCLE

The Brayton Cycle program lasts 18 minutes and has sixty-seven 35mm color slides plus sixteen multi-choice question slides placed at different intervals throughout the program. This program is mostly automatic advance except for 15 slides which the student might want to study for some time; therefore, stop pulses were recorded after these.

A basic closed cycle schematic consisting of a compressor, turbine, and two heat exchangers is described. A steady flow analysis of each component is accomplished by evaluating its work or heat quantity for the case of an arbitrary fluid. Then the fluid is assumed to be a perfect gas and the work and heat quantities are expressed in terms of temperatures. The efficiency of an ideal cycle is then related to the pressure ratio across the compressor. Real cycles, effects

of machine efficiency and pressure drops are also discussed along with cycle modifications such as regeneration, stage compression with intercooling, and staged expansion with reheat. An example problem is worked to familiarize the student with the use of the equations and to bring out the significant feature that the work input is a large percentage of the work output. This leads to a discussion of the critical effects of compressor and turbine efficiencies. The program closes with a discussion of open cycles and this section features detailed photos of a cutaway jet engine.

B. THRUST, POWER, AND EFFICIENCY

This program lasts 27 minutes and has seventy-seven color slides plus eighteen multi-choice question slides also placed at intervals throughout the program. This program is quite long, so a brief intermission was placed halfway through the lesson. This program is not automatic as stop pulses were recorded after every slide.

A general equation for the net propulsive thrust of an arbitrary propulsion system is developed in detail. First, the fluid inside the propulsive device is analyzed by the control volume technique to determine the force of the engine on the fluid. Second, the device is analyzed to account for both the internal and external forces that exist. The effective exhaust velocity is then explained and incorporated into the net thrust equation. The equation is examined and simplified for various cases of air breathing engines and rockets.

Performance parameters, such as specific impulse and specific fuel consumption are discussed. The different measures of power associated with propulsion systems (power input, propulsive power, and thrust power) are carefully defined. Various efficiency parameters (thermal, propulsive, and overall) are then expressed in terms of these different power quantities. Propulsive efficiency is examined in detail for ideal propulsion systems and simple expressions for this important parameter are developed for both air breathers and rockets. This leads to a discussion on the problems of optimizing both thrust and efficiency. An example problem dealing with a turbo-jet propulsion system illustrates the use of equations developed in this program.

V. STUDENT REACTION TO PROGRAMS

A questionnaire was filled out by each student who saw either one of the programs, and a copy of this questionnaire is contained in Appendix C. The objective of the questionnaire was twofold: first to evaluate the academic worth of each program, and second to identify any mechanical problems associated with the hardware. Suggestions received from the students concerning The Brayton Cycle Program were incorporated into the Thrust, Power, and Efficiency Program; i.e., the former program was mostly automatic advance whereas the latter program was strictly manual advance.

A. RESULTS

Ten people viewed the Brayton Cycle Program and four viewed the Thrust Program. All except one student expressed a desire for a manual advance mode. Sixty percent of the students wanted an audible "beep" tone on the tape to indicate those slides which one must manually advance. Most students said both programs were "about right" in length; two said the Brayton Program was too long. Most said the number of questions was "about right"; two expressed a desire for more questions. Around half the students would use these programs as a review and the other half would use them as a first exposure. One student would use them in both circumstances. The art work (all of which was prepared by the author) was acceptable to all. Seventy percent felt that there is a need for these programs while thirty percent had no strong

opinion. Some of the topics which students would like to see made into programs are: fluid mechanics, dynamics, structures, aerodynamics, discussions on entropy and enthalpy, thermodynamics, the Carnot cycle.

Several interesting comments were mentioned which never occurred to the author. One student would like to "back up" the audio, i.e. listen to the narration of a particular slide again. Another student was very vehement about his views concerning teaching aids. He said that teaching aids are <u>aids</u> and should supplement the lecture, not replace it. The teacher is neglecting his duty if he resorts to devices or machines to transmit information and then has no further contact with the student. He further suggested that the entire apparatus be placed in a separate room so that three or four students could view the program simultaneously and discuss the material. Some equipment problems were noted and recommendations concerning these are made in Section VI.

B. ANALYSIS

The Brayton Cycle program was intended to be as automatic as possible. The slides appeared on the screen for the duration of their respective narration. Certain slides, which the author thought would require extra viewing time, had stop pulses recorded after them. But the students needed extra time on many slides so stop pulses were recorded after each slide on the Thrust program. Since a majority of the students desired to hear a "beep" tone for the manually advanced slides, this tone will be incorporated on future

programs. Concerning the "intermission" slide about halfway through the Thrust program, it was found that students didn't need a break and continued to the next slide. Since the students split evenly on when the program should be used, it should be available for use whenever desired. The student comment concerning "backing up" the audio is not feasible with this Coxco unit because synchronization between the audio and video would be lost. Such a convenience is automatically incorporated into the "Sound-on-Slide" system manufactured by 3-M. However, the Sound-on-Slide also has drawbacks such as the 30 second audio limitation, and expensive carriers (slide mounts).

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

There are certain advantages of audio-visual programmed instruction over the lecture and textbook method. They are:

1. Standardization of the material taught.
2. Students can progress at their own pace.
3. Everyone should know the material thoroughly after he completes the program.

The student reaction was quite favorable as evidenced by the additional topics which the students would like to see made into programs. The programs should be neither completely automatic nor completely manually advanced, but some combination of these. Although most students wanted to advance all slides manually, some of the slides are of such an elementary nature that making the student advance these would be a complete waste of time.

No formal tests have been administered to evaluate the degree of learning one receives from these programs; at the present time the programs are complements to the standard course and the results of the questionnaire indicate that this is the desired use.

B. RECOMMENDATIONS

Several mechanical problems were encountered with the Coxco unit; e.g., slides jammed, the Respondex didn't always advance the program, the Respondex question-setting lever would occasionally not advance, and the viewing screen

couldn't accommodate the entire slide. Since the slide trays only hold 36 slides, several trays had to be used during a single program; however, this presented only a minimal inconvenience.

If a Respondex keyboard isn't compatible with a particular slide-tape unit, there are alternate methods of answering the questions. Immediately after the multi-choice question slide, a slide may be placed with the correct answer. Another approach would be to provide the correct answer by audio; and, if appropriate, the narration could also explain why the other choices are incorrect.

An effort should be made to find a better machine. One possibility is a Wollensak Programmer which can be used in conjunction with a standard Kodak Carousel projector. It is further recommended that additional programs be produced and that a thorough evaluation be conducted to see how the "teaching machine" students compare with the other students.

APPENDIX A: THE BRAYTON CYCLE

1 (Title Slide)

2 All craft which move through a fluid medium must operate by some form of a reaction propulsion system. We will not attempt to discuss all types of these systems but will concentrate on those used for aircraft or missile propulsion and are popularly thought of as "jet propulsion devices." Working with these systems permits a natural application of your knowledge in the field of gas dynamics.

3 These engines can be classified as either air-breathers (such as turbo-jet, turbo-fan, turbo-prop, ram jet, and pulse jet) or non air-breathers which are called rockets. Many schemes for rocket propulsion have been proposed but we will only discuss the chemical rocket. Before considering these various propulsion systems we must first carry out a thermodynamic cycle analysis.

4 A number of modern power plants as well as most of the air-breathing engines previously mentioned operate on the same basic thermodynamic cycle which was developed about 100 years ago by George B. Brayton. Although his first model was a reciprocating engine, we shall soon discover that this cycle has certain features which destined it to become the basic cycle for all gas turbine plants.

5 We shall first examine a closed Brayton Cycle in order to develop some of the characteristic operating parameters.

6 The cycle includes a compression process from 1 to 2 with work input designated as W_c ,

7 a constant pressure heat addition process from 2 to 3 with the heat added denoted by q_a ,

8 an expansion process from 3 to 4 with the work output designated as W_t .

9 and a constant pressure heat rejection from 4 to 1 with the heat rejected denoted by q_r .

10 We shall initially make an analysis of an <u>ideal</u> cycle. That is, we shall assume no pressure drops in the heat exchangers, no heat loss in the compressor or turbine, and all reversible processes.

11 Our cycle then consists of:

two reversible adiabatic processes and

two reversible constant pressure processes.

It will be instructive to look at an h-s diagram for the Brayton Cycle. Keep in mind that the working medium for this cycle is in a gaseous form and thus this h-s diagram is similar to a T-s diagram. In fact for perfect gases the diagrams are identical.

12 Since the compression process from 1 to 2 is assumed to be both reversible and adiabatic it is also isentropic.

13 The heat addition occurs reversibly from 2 to 3 at constant pressure.

14 The expansion process from 3 to 4 is another reversible adiabatic, and thus isentropic process.

15 The cycle is closed from 4 to 1 with rejection of heat reversibly at constant pressure.

We shall now proceed to make a steady flow analysis of each portion of the cycle.

F-1 Question concerning name of the cycle.

F-2 Question concerning processes involved in the cycle.

16 We start by examining the work output of the turbine. We first write an energy equation for the control volume which includes the turbine. Since it is adiabatic, the heat transfer term is eliminated and we can easily see that the turbine work output is equal to $h_{t_3} - h_{t_4}$.

17 Analysis of the compressor is quite similar. In this case we designate W_c as the positive quantity of work which is put into the compressor. Thus W_c is equal to $h_{t_2} - h_{t_1}$.

18 One of the most significant quantities of any power cycle is the net work output. The net work is equal to $W_t - W_c$ and can be expressed by the enthalpies as shown . . .

19 We now give consideration to the heat transfered in the cycle, starting with an analysis of the exchanger where heat is added. No shaft work is done in this process and we see that q_a is equal to $h_{t_3} - h_{t_2}$.

20 Analysis of the other heat exchanger is quite similar. If we denote q_r as the positive quantity of heat which is rejected from the system, then q_r is equal to $h_{t_4} - h_{t_1}$.

21 The net heat added is frequently of interest and is equal to $q_a - q_r$ . . . .

22 Careful examination of the expressions that we have developed for w_n and q_n reveals that these quantities are identical. This should not be surprising since we know from the first law of thermodynamics that for any cycle the net work done must equal the net heat added.

F-3 Question dealing with turbine work output (in terms of enthalpy).

F-4 Question dealing with compressor work output (in terms of enthalpy).

F-5 Question dealing with heat addition (in terms of enthalpy).

23 Perhaps the most important parameter of any power cycle is its thermodynamic efficiency. This is defined as the net work output divided by the heat input.

24 For the Brayton Cycle, the thermodynamic efficiency can be expressed in terms of enthalpies as shown. Rearrangement of the numerator permits writing the efficiency in a simpler form. This form can be recognized as being equal to one, minus q_r over q_a . Notice that the efficiency can be expressed solely in terms of the heat quantities.

25 This last result should not be unexpected since we could have immediately substituted the net heat for the net work in the numerator of the efficiency expression. This procedure would have quickly led to the desired result.

All of the expressions that we have developed so far are valid for any fluid.

● F-6 Question dealing with definition of Cycle Thermodynamic Efficiency.

● F-7 Question dealing with computation of Thermodynamic Efficiency (in terms of enthalpy).

● 26 If the working medium is assumed to be a perfect gas, then the h-s diagram can be labeled as a T-s diagram. Further; additional relationships can be brought into play.

● 27 For instance, all of the heat and work quantities can be expressed in terms of temperatures since for perfect gases enthalpy is a function of temperature only. If specific heats are assumed constant then enthalpy differences are easily calculated in terms of the corresponding temperature differences.

● 28 Thus the general equation for cycle efficiency can be written in terms of the temperatures as shown . . . . With a little manipulation this can be put into an extremely simple and significant form. Let us digress for a moment to show how this can be done.

● F-8 Question dealing with computation of Thermodynamic Efficiency (perfect gas medium).

● 29 Looking at the T-s diagram we notice that the entropy change calculated between points 2 and 3 will be the same as that calculated between points 1 and 4 .

30 Now the entropy change between any two points, say A and B , can be computed in terms of the temperatures and pressures by the equation shown. If we are dealing with a constant pressure process the last term in this expression is zero and a simple relation for entropy change results.

31 This relation is applicable to the two constant pressure processes in question. With specific heat considered constant this shows a unique relationship among the four temperatures.

32 We now return to the expression for the cycle efficiency. With a little algebra it is easy to show that under the condition we have just developed — that is — T_{t_3} over T_{t_2} equals T_{t_4} over T_{t_1} , the cycle efficiency can be expressed in terms of the temperature at points 1 and 2 only.

33 Now since the compression process between 1 and 2 is isentropic, this temperature ratio can be related to a pressure ratio.

34 If we designate the pressure ratio of the compression process as r_p , then the thermal efficiency of the Brayton Cycle can be expressed in terms of only r_p and the specific heat ratio as shown. Remember that this relation is only valid for an ideal cycle and when the working medium is considered to be a perfect gas.

35 A plot of this equation shows the influence of the compressor pressure ratio on cycle efficiency. Even for real power plants the pressure ratio remains as the most significant basic parameter.

Normally in closed cycles all velocities in the flow ducts (stations 1, 2, 3, and 4) are relatively small and may be neglected. Thus, all enthalpies, temperatures, and pressures in the equations that have been developed can be treated as static quantities. However, this simplification can not be made with open systems that are used for propulsion systems.

F-9 Question concerning most important parameter affecting cycle efficiency.

36 The following example will serve to illustrate one of the most important characteristics of the Brayton Cycle. Air enters the compressor at 15 psia and 550°R. The pressure ratio is 10. The maximum allowable cycle temperature is 2000°R. Consider an ideal cycle with negligible velocities and treat the air as a perfect gas with constant specific heats. We wish to determine the turbine and compressor work and the cycle efficiency.

37 Knowing the pressure ratio we can easily determine the temperature ratio from the isentropic relations. Since this is an ideal cycle this ratio applies to both the compressor and the turbine and the unknown temperatures are easily computed . . .

38 The enthalpy differences needed to compute the turbine and compressor work are computed in terms of c_p and the respective temperature differences . . .

39 The heat added is computed in a similar fashion, and then the cycle efficiency can easily be found . . .

40 Notice that even in an ideal cycle the net work is a rather small proportion of the turbine work. By comparison, in the Rankine cycle (which is used for steam power plants) about 99% of the turbine work remains as useful work. This radical difference is accounted for by the fact that in the Rankine cycle the working medium is compressed as a liquid whereas in the Brayton cycle the fluid is always in a gaseous form.

41 This large proportion of "back work," or work that must be put into the cycle, accounts for the basic characteristics of the Brayton cycle. First, large volumes of gas must be handled in order to obtain reasonable capacities. For this reason the cycle is particularly suitable for use with turbomachinery. Secondly, machine efficiencies are extremely critical to economical operation. In fact, efficiencies which could be tolerated in other cycles would reduce the net output of a Brayton cycle to zero.

42 This latter point highlights the stumbling block which for years prevented exploitation of this cycle, particularly for purposes of aircraft and missile propulsion. Efficient, lightweight, high pressure ratio compressors were not available until quite recently. Another problem concerns the temperature limitation where the gas enters the turbine. The turbine blading must be able to continuously withstand this temperature while operating under high stress conditions.

F-10 Question concerning significance of "back work."

43 The basic cycle performance can be improved by regeneration, staged compression with intercooling, and staged expansion with reheat.

44 If the turbine outlet temperature T_4, is significantly higher than the compressor outlet temperature T_2, some of the heat that would normally be rejected can be used to furnish part of the heat added. In the diagram shown, the heat removed from 4 to 4' is used to raise the temperature from 2 to 2'. This is called "regeneration" and the net result is a considerable improvement of efficiency, since the amount of heat which must be supplied externally (to go from 2' to 3) has been reduced.

45 One can also accomplish the compression process in stages with "intercooling," or heat removal, between each stage. This procedure reduces the amount of compressor work involved in going from p_1 to p_2.

46 Similarly, the expansion can take place in stages with "reheat," or heat addition, between stages. This increases the amount of turbine work during an expansion from p_3 to p_4.

47 Unfortunately, staged compression and expansion slightly decrease the cycle efficiency but this can be tolerated in order to increase the net work produced per unit mass of fluid flowing. This is called the "specific output" of the cycle and is an indication of the size of unit required to produce a given amount of power.

48 The thermodynamic efficiency of 48.5% calculated in the previous example is quite high because the cycle was assumed to be ideal. To obtain more meaningful results we must account for the harsh realities of life--flow losses. We have already touched on the imporance of having high machine efficiencies. Relatively speaking, this is not too difficult to accomplish where an expansion takes place as is the case in the turbine, but it is quite a task to build an efficient compressor. In addition, pressure drops will be involved in all ducts and especially in the heat exchangers such as the burners, intercoolers, reheaters, and regenerators.

49 Here is an h-s diagram for a real Brayton cycle which shows the effects of machine efficiencies and pressure drops. Note that the irreversible effects cause entropy increases in both the compressor from 1 to 2 and in the turbine from 3 to 4 .

50 Turbine efficiency is defined as the actual work output divided by the work output of an ideal turbine.

51 In this h-s diagram we have shown both the actual turbine process from 3 to 4 and the ideal process from 3 to 4s . Note that both turbines are assumed to operate between the same pressures. Recall that if heat losses are negligible, turbine work is represented by the total enthalpy difference, resulting in the simple expression for efficiency shown.

F-11 Numerical problem involving calculation of turbine work.

52 Compressor efficiency is defined as the ideal work input divided by the actual work input.

53 In this h-s diagram we show the actual compressor process from 1 to 2 together with the ideal process from 1 to 2s . Again, note that both the actual and ideal machines operate between the same pressures. The compressor efficiency is also expressed in terms of the total enthalpy differences as shown . . .

F-12 Numerical problem involving calculation of compressor work.

F-13 Numerical problem involving calculation of net work.

F-14 Numerical problem involving calculation of thermodynamic efficiency.

54 Up to this point we have been discussing "closed" Brayton cycles. However, gas turbine engines used for aircraft and missile propulsion operate on what is called an "open" cycle.

55 In an open cycle the process of heat rejection (from the turbine exit to the compressor inlet) does not physically take place within the engine, but occurs in the atmosphere. Thermodynamically speaking, open and closed cycles are identical but there are a number of significant differences in actual hardware which we shall briefly mention.

56 The air enters the propulsion system at high velocity and thus must be diffused before being allowed to pass into the compressor. A significant portion of the compression occurs in this diffuser. If flight speeds are supersonic, pressure increases also occur across the shock system at the front of the inlet.

57 The heat addition is carried out by an internal combustion process within a burner or combustion chamber. Thus the products of combustion pass through the remainder of the system.

58 After passing through the turbine the air leaves the system by further expanding through a nozzle. This increases the kinetic energy of the exhaust gases which aids in producing thrust.

59 Although the compression and expansion processes generally occur in stages (most particularly with axial compressors) no intercooling is involved.

60 Thrust augmentation with an "afterburner" could be considered as a form of reheat between the last turbine stage and the nozzle expansion. The use of regenerators is impractical for flight propulsion systems.

61 In some parts of the engine high velocities are involved. Thus, the difference between static and stagnation state points must be carefully accounted for. The division of the compression process between the diffuser and compressor and the amount of expansion that takes place within the turbine and the exit nozzle varies greatly depending upon the type of

propulsion system involved. This will be discussed in greater detail in another presentation which describes a number of common propulsion engines.

● F-15 Question dealing with Open Cycle versus Closed Cycle.

● F-16 Question dealing with methods for increasing performance.

● 61a In summary, an analysis of the ideal Brayton Cycle revealed that its thermodynamic efficiency is a function of the pressure ratio. Perhaps the most significant feature of this cycle is that the work input is a large percentage of the work output. Because of this, machine efficiencies are most critical in any power plant operating on the Brayton cycle. Also, to produce a reasonable quantity of net work, large amounts of air must be handled which makes this cycle particularly suitable for turbomachinery.

● 62 If any of the points that have been discussed in this presentation need further clarification it is recommended that you read the associated text. A number of homework problems will also be suggested so that you might gain a better grasp of this material. When you have completed this section you should be able to demonstrate your understanding of the material in the following ways:

● 63 Describe the Brayton cycle and draw h-s diagrams for both ideal and real power plants . . .

● 64 Analyze both the ideal and real cycles.. Compute all work and heat quantities as well as the cycle efficiency. . .

65 State the distinguishing feature of the Brayton cycle that makes it ideally suited for turbomachinery.. Explain why machine efficiencies are so critical in this cycle. . . Discuss the difference between an open and a closed cycle . . .

66 (Credit slide)

APPENDIX B: THRUST ~ POWER ~ AND EFFICIENCY

1 In this presentation we shall examine reaction propulsion systems and obtain a general expression for their net propulsive thrust. We shall then continue to develop some significant performance parameters such as power and efficiency and note the form that these relations take for individual propulsive devices.

2 To determine thrust we need to introduce the momentum equation into the analysis of an arbitrary propulsive device.

3 Consider an airplane or missile which is traveling to the left at a constant velocity V_o. The thrust force is the result of interaction between the fluid and the propulsive device. The fluid pushes on the propulsive device and provides thrust to the left or in the direction of motion, whereas the propulsive device pushes on the fluid opposite to the direction of flight.

4 We start by analyzing the fluid as it passes through the propulsive device.

5 This represents a schematic of any propulsive device. We define a control volume which surrounds all of the fluid inside the propulsion system. Velocities are shown relative to the device, which is used as a frame of reference. The positive x axis is to the right as shown.

6 Recall the momentum equation for a control volume. The sum of all forces on the fluid within the control

volume equals the rate of change of momentum of the fluid inside the control volume plus the net momentum flux out of the control volume.

7 We first take the x-component of this equation and then simplify it for steady flow . . .

8 For one-dimensional flow the surface integral is easy to evaluate as ρ and V are constant over any given cross section. For our case, the integral can be expressed in terms of the flow rates and velocity components at entrance and exit. Furthermore, since the x-axis has been aligned with the velocity vectors, the x-components are the velocities themselves. We must now carefully evaluate all forces on the fluid within the control volume.

9 First consider the interaction between the fluid and the walls of the propulsive device. We define an "enclosure" force as the vector sum of the friction forces and the pressure forces of the wall on the fluid within the control volume.

10 We shall designate F_{enc} as the x-component of this enclosure force . . .

11 We now return to the diagram and indicate the forces acting on the control volume. In addition to the enclosure force pressure forces act over each end of the control volume. Carefully summing the x-components of these forces we obtain the left side of the momentum equation as $p_1A_1 - p_2A_2 + F_{enc}$.

● 12 Substitution of these forces into our momentum equation gives the final relation shown . . .

● 13 You can now solve this equation for F_{enc} . Notice that this enclosure force, which is an extremely complicated summation of internal pressure and friction forces, can easily be expressed in terms of known quantities at the inlet and exit. This shows the great power of the momentum equation.

● 14 You may remember from some previous work that this combination of variables frequently appears and we sometimes define a "thrust function" as $pA + \frac{\dot{m}V}{g_c}$.

● 15 The introduction of the thrust function permits writing the x-component of the enclosure force on the fluid in a very simple form. We shall use this result in the next analysis.

● E-1 Question dealing with evaluation of net momentum flux integral.

● E-2 Question dealing with the definition of the Enclosure Force.

● E-3 Question dealing with force summation on the control volume.

● E-4 Question concerning definition of the Thrust function.

● 16 We now analyze the forces on the enclosure or propulsive device.

17 Remember, we have previously determined that the enclosure is pushing on the fluid with a force of equal magnitude F_{enc} to the right. . . Thus, the fluid must be pushing on the enclosure with a force equal magnitude to the left. This is the internal reaction of the fluid and is designated as F_{int} .

18 F_{int} is thus defined as the positive thrust which arises from the internal fluid forces pusing on the enclosure. The magnitude of F_{int} is equal to that of F_{enc} .

19 In this sketch we have indicated the forces on the enclosure or propulsive device. Besides the internal forces there are external forces. We have shown these external forces as being ambient pressure over the entire enclosure. At first you might say that this picture is incorrect since the pressure really is not constant over the external surface. Furthermore, there are no frictional forces indicated over the external surfaces.

20 The answer is that these differences are accounted for when the drag force is computed, since the drag force includes an integration of the shear stresses along the surface and also a pressure drag term which, by convention, is computed with reference to the ambient pressure.

21 This integration for pressure drag is carried out over the entire external surface of the device and dA_x represents the projection of the increment of area on a plane perpendicular to the x-axis.

22 Recognizing how the friction and pressure drag calculations are made we can agree that the constant ambient pressure representation over the external surface is proper for computing the net positive thrust.

23 We define F_{ext} as the positive thrust which arises from the external forces pushing on the enclosure. Since this has been represented as a constant pressure, the integration of these forces is quite simple.

24 The first term in this expression represents positive thrust from the pressure forces over the rear portion of the propulsive device. The second term represents negative thrust from the pressure forces acting over the forward portion. The final result is p_o times the difference between inlet and outlet areas . . .

25 The net positive thrust on the propulsive device will be the sum of the internal and external forces.

26 Substitution of the previously developed expressions for the internal and external forces yields a relatively simple equation in terms of the thrust function. Further substitution results in the more meaningful expression shown.

27 This equation has been slightly rearranged and in this form can apply to all cases; that is, $\dot{m}_2$ can be different from $\dot{m}_1$ if it is desired to account for the amount of fuel added, p_2 may be different than p_o for the case of sonic or supersonic exhausts, and p_1 may not be the same as p_o .

E-5 Question dealing with internal and external forces on the enclosure.

E-6 Question concerning definition of the external force.

E-7 Question concerning the evaluation of external force.

28 If p_1 is not equal to p_o then V_1 is not equal to V_o . An example of this is shown for subsonic flight. In this particular example the flow system is choked and an external diffusion with flow "spill-over" occurs. That fluid which actually enters the engine is said to be contained within the "pre-entry streamtube."

29 It is customary in the field of propulsion to work with the free stream conditions (p_o and V_o) that exist far ahead of the actual inlet. Thus, by applying this equation between sections zero and two we obtain a simpler expression for the net propulsive thrust which is much more convenient to use . . . It should be clearly noted that these two equations are not equal since the last one, in effect, considers the region from zero to one as part of the propulsive device. Thus, this equation includes the "pre-entry thrust" or propulsive force that the surrounding fluid exerts on the boundary of the "pre-entry streamtube."

30 This error will be compensated for when the drag is computed, since the pressure drag must now be integrated from zero to two as shown. The integral from zero to one

is called the "pre-entry drag" or "additive drag" and this exactly balances the pre-entry thrust.

31 We shall briefly discuss a performance parameter called the "effective exhaust velocity."

32 In most propulsion systems the exit pressure (p_2) is greater than the ambient, which is p_o . Thus, the last term in the equation represents positive thrust. If we omit this pressure thrust term we would need a higher exhaust velocity to produce the same net thrust. This velocity is called the "effective exhaust velocity" and is given the symbol V_j .

33 Introducing this concept permits writing the thrust relation in a simpler form. As shown here it is directly applicable to air-breathing engines. This can be further simplified if we assume that the flow rates are equal. This form of the thrust equation reveals an interesting characteristic of all airbreathing propulsion systems. As their flight speed approaches the effective exhaust velocity the thrust goes to zero. Even long before reaching this point the thrust drops below the drag force which is rapidly increasing with flight speed. Because of this, no air-breathing propulsion system can ever fly faster than its exit jet.

34 This fact also helps explain the natural operating speed range of various engines. Recall that the turbo-prop provides a small velocity change to a very large mass of air. Thus, its exit jet has quite a low velocity which

limits the system to low speed operation. At the other end of the spectrum we have the turbo-jet (or pure jet) which provides a large velocity increment to a relatively small mass of air. Therefore, this device can operate at much higher flight speeds.

● 35 All of the equations that we have developed may also be applied to rockets by simply noting that for this case there is no inlet. Thus any term involving the inflow is dropped from the equation.

● 36 The concept of effective exhaust velocity may also be used here to eliminate the pressure thrust term. Note that the propulsive thrust is independent of the flight speed and thus a rocket can easily fly faster than its exit jet.

● E-8 Question concerning the definition of "Effective Exhaust Velocity."

● E-9 Question dealing with air-breathers and rockets.

● 37 Since the thrust of an engine is dependent on its size, the use of thrust alone as a performance criteria is meaningless. We must therefore arrive at a new parameter which combines both thrust and size.

● 38 Specific impulse, which is sometimes called specific thrust, is defined as the net thrust per unit mass flow rate. Note that the units of specific impulse are properly pound force-seconds divided by pounds mass. These are usually erroneously referred to as "seconds."

39 Specific impulse is used mostly for rockets and in this case it can be seen that the effective exhaust velocity becomes quite significant. Air-breathers generally use specific fuel consumption as a performance parameter and this will be explained later.

E-10 Question dealing with units of specific impulse.

39a You are now approximately half way through this lesson. It might be advisable to take a short break before completing this material. Press the restart button when you are ready to continue.

40 There are three different measures of power which are connected with propulsion systems;

41 They are: power input, propulsive power, and thrust power. Consideration of these power quantities enables us to separate the performance of the thermodynamic cycle from that of the propulsion element.

42 The general relationship among these various power quantities is shown in this diagram. The thermodynamic cycle is concerned with power input and propulsive power; whereas the propulsive device is the link between the propulsive power and the thrust power. Let us take a careful look at each of these quantities.

43 The power input to the working fluid is designated as P_I and is the rate at which heat or chemical energy is supplied to the system. The power input equals the fuel flow rate times the heating value of the fuel. This energy is the input to the thermodynamic cycle.

44 The output of the thermodynamic cycle is the input to the propulsion element and is designated as P and called propulsive power. In the case of propeller driven systems the propulsive power is the shaft power supplied to the propeller.

45 For other systems the propulsive power can be viewed as the change in kinetic energy of the working medium as it passes through the system. Note the use of the effective exhaust velocity here. This is the only fair way to compute the propulsive power since there most likely will be some pressure thrust.

46 The thrust power output of the propulsive device is the actual rate of doing useful propulsion work and is designated as P_T . This is equal to the net propulsive thrust times the flight speed.

47 For an air-breathing device, the thrust power takes the form shown. If we neglect the slight difference between the mass flow rates in and out, the expression is further simplified . . .

48 Looking at this expression we can see that the thrust power of an air-breather is zero when the flight speed is either zero or equal to V_j . In the former case we have a high thrust but no motion — thus no power. In the latter case we have previously noted that the thrust is reduced to zero. Somewhere between these extremes there must be a point of maximum thrust power.

49 To find this condition we take the derivative of P_T with respect to V_o , keeping V_j constant. Setting this equal to zero reveals that maximum thrust power results when V_j equals $2V_o$. Remember that this situation only applies to air-breathers.

50 For the case of rockets the thrust power equals $\dot{m} V_j V_o / g_c$. Here, no maximum is reached as the power continually increases with flight speed.

51 We can now develop an alternate method of computing propulsive power by noting that the difference between the propulsive power and thrust power is the lost power P_L . . .

52 The major loss is the <u>absolute</u> kinetic energy of the exit jet and this is an unavoidable loss, even for a perfect propulsion system. In addition to this other energy may be lost. For instance, the exhaust jet may not all be directed axially or it may have a swirl component. In any event, the <u>minimum</u> power loss will be as shown.

E-11 Question dealing with the definition of power input.

E-12 Question dealing with the definition of propulsive power.

E-13 Question dealing with thrust power.

E-14 Question dealing with the lost power of a perfect propulsion system.

53 The identification of the different power quantities permits various efficiency factors to be determined.

54 Thermal efficiency indicates how well the thermodynamic cycle converts the energy of the fuel into work

which is available for use. Thus, it is the ratio of propulsive power to the power input.

● 55 The propulsive efficiency indicates how well the thrust device utilizes the cycle output to actually propel the vehicle. Thus, the propulsive efficiency is the ratio of the thrust power to the propulsive power. An alternate form is also shown in terms of the lost power . . .

● 56 An overall efficiency can also be defined which is a performance index for the entire propulsion system. It is a ratio of the thrust power to the power input; or, it can also be expressed as the product of the thermal efficiency and the propulsive efficiency.

● E-15 Question dealing with the representation of thermal efficiency.

● E-16 Question dealing with the representation of propulsive efficiency.

● E-17 Question dealing with the representation of overall efficiency.

● 57 Let us examine an ideal propulsion system, that is, one in which there are no unavoidable losses.

● 58 The propulsive efficiency is first written in terms of the thrust power and lost power. When general substitutions are made for these quantities the result is valid for all types of propulsion systems.

● 59 We first consider air-breathing engines and substitute the thrust expression for these devices. The resulting

expression is rather formidable but it can be greatly simplified by neglecting the difference between $\dot{m}_o$ and $\dot{m}_2$.

● 60 It will also be helpful to introduce the "speed ratio," ν , which is defined as V_o over V_j .

● 61 Under these conditions the propulsive efficiency for an ideal air-breather can be written as 2ν over $1 + \nu$. This shows that the propulsive efficiency for air-breathers continually increases with flight speed, reaching a maximum when $\nu = 1$, or when V_o equals V_j . This is quite reasonable since under this condition the absolute velocity of the exit jet is zero and there would be no exit loss.

● 62 At this point you can begin to see some of the problems involved in optimizing air-breathing jet propulsion systems. We previously showed that maximum thrust power is attained when V_j equals $2V_o$. Now we see that maximum propulsive efficiency is attained when V_j equals V_o ; but unfortunately for this latter case the thrust is zero.

● 63 For the case of the rocket, substitution of the appropriate power relations yields this equation for propulsive efficiency . . .

● 64 With the introduction of the speed ratio, the propulsive efficiency of an ideal rocket becomes 2ν over $1 + \nu^2$. Like the air-breather, this expression is also maximum when ν equals one; only in this case, the condition is actually attainable.

● 65 Whereas specific impulse is a good overall performance indicator for rockets, specific fuel consumption is a comparable performance index for air-breathing engines.

66 For a propeller driven engine it is based on shaft power and is called "brake specific fuel consumption." The bsfc is defined as the fuel flow in pounds mass per hour divided by the shaft horsepower . . .

67 For all other air-breathers it is based on thrust and is called "thrust specific fuel consumption." The tsfc is defined as the fuel flow rate divided by the net propulsive thrust . . .

68 If we relate the fuel flow to the Power input and substitute for the thrust force in terms of thrust power, we see that the thrust specific fuel consumption is a direct indication of the overall efficiency. Thus, this is the primary economic parameter of any jet propulsion system.

E-18 Question dealing with specific fuel consumption.

69 The following example of a turbo-jet propulsion system will illustrate the use of some relations developed in this lesson.

70 A turbo-jet engine is operating at a flight speed of 872 ft/sec at an altitude where the pressure is 473 psfa. Air enters at the rate of 55 lbm/sec, and we may assume that the mass of fuel added is counterbalanced by the bleed air used to run engine auxiliaries. Thus, the flow rate is considered constant throughout the device. A previous analysis of the internal flow has revealed that the jet exits with a velocity of 1790 ft/sec relative to the engine. It has a pressure of 1300 psfa and requires an exit area of

1.66 ft^2. For the heating value shown the fuel air ratio was calculated to be .02.

71 We now desire to find the net propulsive thrust and the thrust power. Both of these can be calculated by direct substitution into the equations we have developed . . .

72 The power input is then computed which permits the overall efficiency to be determined . . . Finally, the thrust specific fuel consumption is calculated . . . The value of 1.345 for the tsfc is a little high, but this is characteristic of a pure jet engine . . .

73 The net thrust of any propulsive device was derived in terms of the mass flow rates, velocities, and pressures as shown. You should learn this equation as it is probably the most important relation in this lesson. Also, you should not overlook the various power and efficiency parameters. Perhaps the most interesting of these is the propulsive efficiency since this is a measure of what the propulsive device is accomplishing, exclusive of the energy producer. This is expressed here in terms of the speed ratio for both air-breathers and rockets. We noted that for air-breathers maximum efficiency occurs at the point of minimum thrust, whereas rockets are not subject to this dilemma. Other important performance indicators are thrust specific fuel consumption and specific impulse.

74 If any of the points that have been discussed in this presentation need further clarification it is recommended that you read the associated text. A number of homework

problems will also be suggested so that you might gain a better grasp of this material.

● 75 When you have completed this section you should be able to demonstrate your understanding of the material in the following ways:

Develop the expression for the net propulsive thrust of an arbitrary reaction propulsion system . . .

Define or give expressions for specific fuel consumption, effective exhaust velocity, specific impulse, power input, propulsive power, thrust power, thermal efficiency, propulsive efficiency, and overall efficiency.

● 76 Compute the significant performance parameters for a propulsion system when given appropriate velocities, areas, pressures, etc. . . Derive an expression for the ideal propulsive efficiency of an air-breathing engine and a rocket engine in terms of the speed ratio ν .

● 77 This completes the lesson on thrust, power, and efficiency of reaction propulsion systems. Make certain that all equipment is properly secured as described in the operating instructions.

APPENDIX C: QUESTIONNAIRE ON PROGRAMMED LEARNING

Near the end of your Thermo course, and again near the end of your Gas Dynamics course, you were given an opportunity to try some instructional programs on the subject of Reaction Propulsion Systems. These slide-tape programs are the result of a thesis project which involved considerable time and effort and it is our desire to assess their worth. Your cooperation in completing this questionnaire as soon as possible will be appreciated. Please return to LT Bellinoff's mail box (Section AD24) outside the Curricular Office.
Thank you -

1. Check the programs that you used.

   ☐ The Brayton Cycle

   ☐ Thrust, Power, and Efficiency

   ☐ Neither

   (If you checked the last box you need not read any further — But please return this questionnaire.)

2. For the Brayton Cycle program all slides advanced automatically (except for the question slides). For the other program all slides had to be advanced by pushing the START/RESTART button.

   ☐ I would like to have all slides advanced automatically.

   ☐ I would like to advance all slides myself.

   ☐ I would like some combination of these. Explain.

3. Would you like to hear an audible "beep" tone at the appropriate spot for those slides which you must advance with the START/RESTART button?

   ☐ Yes ☐ No

4. What about the length of the programs?

Brayton ☐ Too long ☐ About right ☐ Too short.

Thrust, P. & E. ☐ Too long ☐ About right ☐ Too short.

5. Questions were asked during these programs to provide feedback to the learner. The number of questions was

☐ Too many ☐ About right ☐ Too few

6. Would this type of program be more beneficial to you as

☐ A first exposure to the material? or

☐ As a review of the material?

7. The art work for the slides was not done professionally. Do you feel that the quality of the slides was acceptable?

☐ Yes ☐ No ☐ No strong opinion

8. Do you feel that there is a need for programs of this type at the Postgraduate School?

☐ Yes ☐ No ☐ No strong opinion

If you answered yes, what particular subject matter would you like to see? Be as specific as possible.

9. There were a number of technical difficulties such as hot air blowing directly on the learner, poor audio quality on portions of the tape, improper functioning of the Respondex, etc. We believe that these can be easily solved by different programming techniques and more reliable equipment. Meanwhile, if you have any comments or suggestions concerning this project, please write them below (or on the reverse of this sheet).

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

In an attempt to improve upon the traditional "lecture and textbook" mode of teaching, an Audio-Visual Response Teaching Machine was utilized for certain topics in gasdynamics. This teaching system was based on three elements: programmed instruction, a Question/Response/Answer technique, and continuous confirmation of answers. The teaching machine is a portable self contained unit consisting of a dual track

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(20. ABSTRACT continued)

cassette tape recorder, viewing screen, slide magazines, remote control, and a Respondex keyboard. Detailed scripts (including multiple-choice questions) were written, slides were prepared and synchronized audio-visual programmed lessons were assembled. The results are two individual packages on Reaction Propulsion Systems: The Brayton Cycle and Thrust, Power and Efficiency. Student reaction to these programs was favorable. It was concluded that this method should be used in a supplemental capacity to the course and recommended that work in this field continue.

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