INTRODUCTION TO THE
MIT GAS TURBINE LABORATORY

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TABLE OF CONTENTS

1.0 Introduction .......................................................... 3
2.0 Brief History and Background of the GTL .................. 3
3.0 Current Research Projects of the GTL ....................... 4
4.0 Laboratory Equipment ............................................ 5
5.0 Organization of the GTL ......................................... 6
6.0 Computers ........................................................... 7
7.0 Laboratory Safety .................................................. 8
8.0 Accounting Procedures ........................................... 8
9.0 Seminars ............................................................. 9
10.0 Gas Turbine Laboratory Library ............................... 9
11.0 Working Hours ..................................................... 10
12.0 Security and Personal Safety .................................. 10
13.0 Working and Studying at the GTL ......................... 11
Appendix I: Research in the MIT Gas Turbine Laboratory ... 12
Appendix II: Purchasing Procedures ............................... 13
Appendix III: MIT Billing and Shipping Information .......... 14
1.0 Introduction

Welcome to the Gas Turbine Laboratory (GTL) of the Massachusetts Institute of Technology. The GTL has had a worldwide reputation for research and teaching at the forefront of gas turbine technology for over 60 years. The lab is a reflection of the shared interest of its faculty and staff in both working at the frontiers of aero-propulsion and educating graduate students in this technology. We work in this area because we find it rewarding and exciting, and hope that we can transmit this excitement during your stay. The performance of gas turbine engines has improved enormously over the past 60 years and will continue to do so for quite some time.

The purpose of this handout is to acquaint you with the GTL – to give you an idea of what to expect and what is expected of you. Additional information may be found in the Graduate Student Manual available from your department’s Graduate Office.

2.0 Brief History and Background of the GTL

The concept of an MIT Gas Turbine Laboratory was formulated not long after the first jet engines were successfully run. Shortly after the end of the Second World War, Professor J.C. Hunsaker, who was one of the pioneers of aviation in this country and who was a member of the original National Advisory Committee on Aeronautics (the forerunner of NASA), brought together a group of American industries who donated funds for the construction of a laboratory devoted to jet propulsion. A plaque commemorating this now hangs in the main laboratory.

From that beginning the GTL evolved into what we believe is a world-class institution for teaching and research in aero-propulsion and turbomachinery technology. The research carried out in the laboratory has changed with the interests of the participants, but we have always sought to carry out the type of work that leads, rather than follows, the state of the art.

Examples of current and past research projects include: engine diagnostics and smart engines, aerodynamically induced compressor rotor whirl, a criterion for axial compressor hub-corner separation, axial and centrifugal compressor stability prediction, losses in centrifugal pumps, loss generation mechanisms in axial turbomachinery, the Silent Aircraft Initiative (a collaborative project with Cambridge University, Boeing, Rolls Royce, and other industrial partners), hybrid-wing-body airframe design and propulsion system integration for reduced environmental impact (NASA N+2), counter-rotating propfan aerodynamics and acoustics, an engine air-brake for quiet aircraft, inlet distortion noise prediction for embedded propulsion systems, novel aircraft concepts for 2035 (NASA N+3), high-speed micro gas bearings for MEMS turbomachinery, small gas turbines and energy concepts for portable power, and carbon-nano-tube bearings.

The laboratory maintains strong ties with industry and government research in the area of propulsion and turbomachinery technology, as well as with other academic institutions who are leaders in this field. We have, for example, collaborative projects with major American aeroengine manufacturers, as well as European and Japanese companies, so that there are many connections between the work in the GTL and “real world” problems. Research support also comes from different NASA centers. Research is often carried out at government or industry facilities. We also have longstanding interactions with Caltech and with the Whittle Laboratory at Cambridge University in England.
We view these different ties, and the interchange of ideas that results from them, as a very positive aspect of the way in which the laboratory operates. On a more personal basis, the close links to the outside world means that students often have the opportunity to present work directly to outside sponsors, to conferences, or to other individuals from academia, industry, or government. This, in itself, is a valuable part of the educational process.

### 3.0 Current Research Projects of the GTL

The Gas Turbine Laboratory is a busy place. New projects are continually starting and old ones being phased out. The GTL web site (http://web.mit.edu/aeroastro/labs/gtl/index.html) has a more or less current list of project titles and the names of the associated faculty and staff. Table 3.1 summarizes a number of ongoing projects. Additional information on the research projects is given in Appendix I.

**TABLE 3.1**

**LIST OF RECENT/CURRENT RESEARCH PROJECTS**

- A Unified Approach for Vaned Diffuser Design in Advanced Centrifugal Compressors
- A Methodology for Centrifugal Compressor Stability Prediction
- Small-Scale Gas Turbine Engines
- Improved Performance Return Channel Design for Multistage Centrifugal Compressors
- Aeromechanic Response in High Performance Centrifugal Compressor Stage
- Ported Shroud Operation in Turbochargers
- Secondary Air Interactions with Main Flow in Axial Turbines
- Compressor Aerodynamics in Large Industrial Gas Turbines for Power Generation
- Loss Modeling of Turbine Tip Leakage Flows
- The "Swirl Tube" - an Aircraft Drag Management Device to Reduce Noise and Fuel Burn
- A Noise Assessment Methodology for Highly-Integrated Propulsion Systems with Inlet Flow Distortion
- Propulsion System Integration and Noise Assessment of a Hybrid Wing-Body Aircraft
- Carbon Nanotube Bearings
- Assessment of Propfan Propulsion Systems for Reduced Environmental Impact
- Low FPR Propulsion Noise and Performance in Ultra-Short Nacelles
- CO₂ Compressor Design
4.0 Laboratory Equipment

The GTL has several million dollars worth of laboratory equipment used in the research. This equipment falls into one of two categories: shared equipment "owned" by the lab, and equipment which "belongs" to individual research projects. The first category consists of such items as the large air supplies, wind tunnels, machine tools, power supplies, etc, which are distributed throughout the building. Some of these are listed in Table 4.1. This equipment is the responsibility of the Laboratory Manager who must be consulted before any item is used. The second category of equipment includes most of the electronic test equipment, instrumentation, and data acquisition equipment, as well as most of the test rigs. These are never touched without the prior approval of the "owner." The specialized test rigs are listed in Table 4.2.

**TABLE 4.1: GAS TURBINE LAB FACILITIES**

--- Shared Facilities ---

1. Oil Free Dry (-40°C) Air
   - Continuous: 750 SCFM at 100 psi
   - Blowdown: 2200 cu.ft. total at 100 psi
2. High Pressure Air
   - Continuous: 2250 psi
   - Blowdown: 22 cu.ft. at 2000 psi
3. Shop Air
4. Continuous Supersonic Wind Tunnel and Air Supply
   - Approximately 15,000 SCFM at 30 psi continuous, blowing or suction
5. Vacuum – 6" steam ejector, 0.5 lb/sec down to 150 mm Hg
6. D.C. Power
   - a) Building D.C.: -250 V
   - b) Small MG Set: 0-250 V at 500 amps
   - c) Large MG Set: 0-600 V at 2200 amps

**TABLE 4.2: SPECIALIZED EXPERIMENTAL FACILITIES**

1. Blowdown compressor (transonic stage)
2. Single-stage (low speed) compressor
3. Blowdown turbine
4. Small gas turbine engine test stands
5. Large shocktube
6. Small shocktube
7. 1 x 1 ft subsonic wind tunnel
8. High pressure shock tube
9. Swirl flow facility (diffusers for centrifugal compressors)
10. Supersonic wind tunnel

The lab maintains a modest stock of commonly used (in the GTL) parts such as fasteners, tube fittings, metal stock, and electronic components. The Lab Manager is responsible for this. In addition, MIT maintains central stockrooms for various types of electronics, chemicals, and laboratory apparatus for which a requisition is required (see the section "Ordering Supplies").
5.0 Organization of the GTL

The Gas Turbine Laboratory is a research organization within the academic department of Aeronautics and Astronautics in the MIT School of Engineering. Faculty, staff, and students are associated with both the GTL and an academic department, usually (but not necessarily) Aero/Astro or Mechanical Engineering. Insofar as the day-to-day operation of the GTL is concerned, departmental affiliation is unimportant. Students may (and generally do) take subjects in several departments. They must, however, abide by the appropriate academic rules and procedures which vary somewhat from department to department (see your department's Graduate Student Manual).

The professional staff of the GTL consists of 4-5 faculty (who may be associated with other labs as well), 1-2 research staff, and 20-25 graduate students. Often, 1 or 2 faculty from other universities, or experienced engineers from industry or government laboratories spend anywhere from a few weeks to several years at the lab. To assist with the experimental work, the lab employs a Laboratory Manager to provide technical support. There are also administrative staff who are concerned with business, fiscal and contractual matters, and editing and publications. It is to be emphasized, however, that the technical content and management of each research project is the responsibility of that project's Principal Investigator.

In the following, you will find a brief description of the job function of the various staff members.

- **Laboratory Director** — Professor Z. S. Spakovszky (31-265) has overall responsibility for the Gas Turbine Laboratory, the disposition of its resources (space, people, money, equipment), and the day-to-day administration.
- **Fiscal Officer** — Jori Barabino (33-214D) is responsible for contractual matters, fiscal oversight, and approval of all purchases and expenditures.
- **Assistant to the Director** — Robin Courchesne-Sato (31-264) is responsible for the day-to-day operation of the GTL headquarters (mail, expense reimbursement, keys) and helps to support faculty/staff with proposal preparation, travel, etc. She is the first person to go to with questions about the GTL. Robin is also responsible for producing GTL reports, papers for publication, technical illustrations, and presentations. This expressly does not include theses, which are the responsibility of the individual students. Responsibilities also include managing the GTL website.
- **Laboratory Manager** — James Letendre (31-261K) manages the departmental machine shop, is responsible for maintenance and upkeep of the laboratory equipment, is the lab safety officer, and interfaces with outside vendors for experimental goods and services. This is a person of wide practical experience with a variety of laboratory techniques. He is the first person to go to with an experimental problem or a scheduling difficulty.
- **Computer Administrators** — For questions regarding computers and the GTL network, please contact Dave Hall or Andreas Peters (31-259) or the Lab Director.
6.0 Computers

The Gas Turbine Laboratory has an internal computer network of considerable size, consisting of desktop workstations, cluster machines for computations, and storage space for data. Each student is provided with an account on the network for performing high performance computations and storing large data files (e.g. CFD solutions).

Computer usage (CPU time, disk storage, printing, etc.) for GTL computers is not explicitly rationed or charged for. Rather, it is expected that common sense and courtesy will prevail. You can use as much computer time as you need so long as this usage doesn't interfere with other users. As the network is run for and by students, communication between users is key in making sure there are enough processors, licenses, etc. for everyone to be able to perform computations in a reasonable amount of time. Ask the Computer Administrator if you have questions. People who abuse the machines will be warned. Continuing abuse will mean loss of computer privileges, which may implicitly terminate employment.

The GTL computer network is paid for by research contracts. Government accounting rules require that government research contracts receive the lowest rate for computer time – effectively forcing all users to pay the same rates. The implication of this is that unfunded "special" projects such as homework or personal studies may not be done on these machines. MIT provides other computer resources for strictly educational usage under Project Athena, and all graduate students may get Athena accounts for no charge.

The computers at the GTL are operated in a "lean and mean" manner. In other words, we have a large amount of hardware and software compared to the computer staff to support it. There are two implications of this. Each user is responsible for backing up their own material in a timely fashion. *It is extremely important that you do this*, as disk failures have been known to occur. The second implication is that the Computer Administrator does not have time to field frequent questions from the many users. Instead, get in the habit of asking obviously non-original questions such as "how do I compile this" or "where are the scientific subroutines," etc. of your colleagues and office mates.

The Computer Administrator is assisted by the computer users. Monthly meetings are held to discuss current issues and to share information. Please join these meetings and, as you become more proficient, even volunteer to help where needed!

There are several lab-owned computers, many of which are on the desks of individual students, which may be used for homework and personal studies. Please do not bring in foreign programs, games, etc. because of the continuing problems with computer viruses.

Technical details and other useful information concerning the workstations used for the bulk of the scientific calculations are on the GTL Network Wiki. The Wiki can be accessed from within a web browser on the GTL network machines at http://gtl-gateway. For help on using the MediaWiki interface to add/edit pages, see [http://www.mediawiki.org/wiki/MediaWiki](http://www.mediawiki.org/wiki/MediaWiki) on the internet.
7.0 Laboratory Safety

Safety in the workplace is a prime concern at MIT, which strictly adheres to all applicable state and federal regulations. In the Gas Turbine Laboratory, safety is the responsibility of everyone, from principal investigators to graduate students. All new students are required to attend a two-hour lab safety lecture before they may work in the lab. In addition, special courses are given as appropriate for those individuals working with particular technologies, lasers for example.

The Lab Manager is also the lab's Safety Officer, and can answer any questions you may have as to approved techniques. Safety is especially important at the GTL since experimental, high speed turbomachinery is not inherently safe. There are many additional hazards in the lab, such as compressed gas, cranes and hoists, high voltage power supplies, and a variety of rotating machinery. Common sense is important but not always sufficient. Strict attention must be paid to the operating instructions.

A seemingly trivial but surprisingly important part of lab safety is neatness. Wires, tubing, etc. underfoot, and apparatus, parts, and tools strewn about are some of the most insidious hazards to both personnel and equipment. (Research compressors, for example, tend to protest when swallowing a wrench or rag, and there have been notable instances where a good deal of time was spent in diagnosing foreign object ingestion.) Therefore, each researcher is expected to keep their area neat and picked up. The Safety Officer must be obeyed insofar as safety is concerned. He has the authority to shut down unsafe experiments or even exclude people from the lab.

The proper handling and disposal of chemicals is an especially important concern. In general, chemicals may not be flushed down the drains. Consult the Safety Officer for the appropriate handling and disposal procedures for each particular chemical. Chemical safety sheets are prominently posted near the ground floor lab stairway.

MIT policy forbids students and employees from working alone with dangerous apparatus (machine tools, rotating test rigs, etc.). During the working day, there are usually people about but nights and weekends can be a problem. You may not operate equipment alone; someone else must be present and aware of your activities. This can be a colleague on the next rig or a non-technical friend. In either case, the person should know emergency shutdown procedures and how to call for help (dial 100). Disobeying this rule can result in revoking of privileges to work in the laboratory.

More safety information will be given at the mandatory safety lecture given at the beginning of each semester. Signs at GTL headquarters will announce the time and place.

8.0 Accounting Procedures

Little at MIT is free (lunch included). All materials and activities – supplies, copying, postage, computer time, technician time, machine shop services, telephone calls, etc. – must be paid for in some manner. At MIT, this is done by charging these activities to appropriate research or academic accounts – represented by seven-digit account numbers. You will be given the number appropriate to your activities. Please use the proper account number at all times. Mistakes generate excessive paperwork. Personal telephone calls, faxes, postage, and copying are not allowed on research accounts. If an emergency comes up and you must make a long distance call, note your name, date and telephone number and give it to Robin, who will forward it to the Fiscal Officer. We will bill
you when the charge appears on the monthly statements. Purposely mischarging to research accounts may be considered fraud, and can result in termination of employment and criminal prosecution. (If you are aware of such activity, please report it to the Laboratory Director.)

During your stay here, you may require supplies, equipment, or services not available in the lab. (Note that office supplies are available from Robin Courchesne-Sato). There are four ways of going about this – purchase reimbursements, internal requisitions, purchase orders, and SAP.

- **Purchase reimbursements** – When you purchase an item for the GTL, please give the receipt to Robin for reimbursement. Please use the MIT tax exemption number when making all purchases (E042-103-594). MIT does not reimburse for sales tax, so if you fail to use the number, you will be stuck with the tax yourself. When purchasing things for the lab at the Coop, give both the tax exemption number and the MIT Coop number (13-3).
- **Internal Materials and Services** – include the VWR stock rooms and machine shops (other than our own). See Appendix II for the procedure. Note that they must be signed by an authorized person – usually the Principal Investigator or Fiscal Officer. Graduate students are not authorized to sign. For some supplies, notably hypodermic needles, precious metals, and ethanol, a Professor's signature is required.
- **External Purchases** – can be placed with purchase orders issued by the Purchasing Department. A requisition is required here. More detail is given in Appendix III.
- **SAP** – is an Institute-wide electronic requisitioning system created for the Institute. This system can be used to create requisitions for P.O.’s for materials and services. Individuals must be signed up in advance. See the Fiscal Officer for more details.

### 9.0 Seminars

There are a large number of technical seminars and lectures given by different organizations at MIT, the Department, and the Institute. The weekly seminars sponsored by the Gas Turbine Laboratory are Tuesdays from 4:30 to 5:30 pm. They are given by both MIT and outside speakers. All GTL students and staff are expected to attend. Various groups within the lab hold weekly informal seminars on specific topics. These are informal work-in-progress talks given by graduate students. You are strongly urged to attend the appropriate ones. Notice of seminars is given in Tech Talk and many are also posted in the GTL and outside Aero/Astro Headquarters (33-207). Also, please volunteer to help out occasionally with the refreshments.

### 10.0 Gas Turbine Laboratory Library

The GTL has a library in 31-253. The library has what can only be described as a some-what random, but still growing, collection of books, reports and journals, all of which are interesting and some even germaine to the work in the Lab. As an example, recent issues of the ASME Journal of Turbomachinery are included; these are not found in the Aero/Astro Library. You will also find an ongoing list of GTL-affiliated publications, both internal and external.

You are encouraged to use the library – both to peruse the collection and as a quiet place to think or work. You may borrow the books but please fill out the library card and give it to Robin in 31-264. (Not all books have cards yet since the library is still being organized.) Please return the books when done as this is a shared resource.
11.0 Working Hours

The GTL has somewhat flexible working hours stretching from 7:00 to 18:00. Research Assistants are considered junior staff members and as such are expected to be at work (in their offices or laboratories) during normal business hours except for time spent in class. The interaction among colleagues is an important part of both the educational process and the research, so that everyone at the GTL is expected to be in during the working day – not "working at home" or "keeping midnight to 8 am hours." Do not work alone in the lab on off hours.

As stated in the Graduate Student Manual, full-time research assistants receive two weeks vacation per year. Since RA's are MIT employees, they receive the same holidays as other employees. These work holidays are considerably fewer than the school holidays, for which classes are cancelled, and RA's are expected to be at work during these class holidays. Talk to your supervisor about absences, sickness, etc. You are expected to notify your supervisor in advance of vacations and absences.

12.0 Security and Personal Safety

MIT is an open campus in an urban environment and, as such, security for people, personal possessions, and equipment is a concern. Although the GTL is relatively isolated, wallets, pocketbooks, computers, and equipment do disappear – often near the start of a term. It is important to keep personal belongings out of sight. Your office and laboratory should be locked when no one is in it, even during the day but especially at night. Some of the labs are alarmed and these should be turned on when no one is around. Equipment is not insured and often cannot be replaced. New equipment and tools should be marked.

The exterior doors to this building are locked after 6 pm and on weekends. You will be issued keys. Do not block these doors open or unlock them – this has led to problems in the past. If you see a door open or unlocked which should not be, please close it. All people authorized for access have keys.

All MIT facilities employees with business in the building carry picture ID's. Also, they have master keys, so be suspicious of anyone who asks you to open a door for them. A common ploy is to ask for a non-existent room number or person. If you see strange or suspicious people about, inform the lab manager or secretary or call the Campus Patrol at ext. 100.

Note that it is especially important to keep rooms with computers locked. If you are about late at night and no one else is, please lock all the doors before leaving.
13.0 Working and Studying at the GTL

Space is very limited at the Gas Turbine Laboratory which means working conditions can be cramped. Sharing of office and lab space is the rule rather than the exception. Courtesy, consideration, and thoughtfulness are thus especially important. Radios should not be played without headphones. Loud discussions (i.e. bull sessions and cell phones) might be best held in the library, conference room, or hall. Personal belongings such as books should not be borrowed without prior permission. Laboratory apparatus and tools should remain untouched without prior permission – including even small items like nuts and bolts, cables, etc. Having to track such things about the lab is always annoying. Please keep the office and common areas clean and neat, especially in regard to food-related items. Please keep the floor space free (i.e. don’t leave bags and other items behind) so that the custodians can sweep the floors. Do not accumulate cans and bottles, and please help keep the building clean. Note that smoking in the building is forbidden by City of Cambridge ordinance.
APPENDIX I
RESEARCH IN THE MIT GAS TURBINE LABORATORY

Specific areas of research in the laboratory include theoretical and experimental study of transonic compressors and turbines, stability of compression systems including engine-airframe integration, active control of aerodynamics and aeromechanical instabilities, computational and experimental study of internal and external heat transfer in turbine blading, performance enhancement of propulsive devices through introduction of streamwise vorticity, turbomachinery tip clearance flows, combustion stability, noise in turbomachinery and exhaust nozzles, unsteady flow in turbomachines, flow control for turbomachinery and inlets, micro gas turbines and rocket engines, and centrifugal compressor and pump performance and stability. Research is supported by government agencies and laboratories as well as a number of industrial sponsors, and there are strong links between work in the laboratory and real-world problems of advanced propulsion devices. Descriptions of current activities can be found on the GTL web site:

APPENDIX II
PURCHASING PROCEDURES

Requisitions are used for purchases internal to MIT as well as to generate purchase orders that go
to outside vendors. All requisitions should be completely filled out (date, your name, room
number, telephone, etc.) on the SAP web site (http://web.mit.edu/sapweb/PS1/index.shtml). They
require a valid cost object number and G/L designation, and need to be routed to an authorized
approver. Requisitions can be used for the different internal partner providers such as VWR,
BOC, Office Depot, and GovConnection, for example.

There is a comprehensive list of vendor names, addresses, and telephone numbers online or in
the rolodex files in 31-264 that you can access to look for vendors and previous purchase orders.
We usually call the vendor for pricing and availability on an item before generating a requisition
for a P.O. number and placing the purchase order with the vendor.

All original packing slips, receipts, bills of lading, air bills, truck receipts, invoices, or any
paperwork that you are not sure about but looks like it might be related to your shipment should
be turned in to Robin in 31-264. It is then matched with the purchase orders and the receiving
documentation. It is very important that this paperwork be turned in promptly. Packing slips
should be checked to make sure you received what you actually ordered, and any back orders or
overshipments should be noted. Confirming purchase orders, requisitions, packing/receiving
documentation, and equipment files are kept in one central location.

Any problems with vendors or customer service matters, such as late deliveries, damaged
shipments, materials that need to be returned to vendors, etc., should be brought to the attention
of the staff promptly. These situations are usually speedily resolved if dealt with as soon as the
problem occurs (rather than leaving the shipment on the lab bench for a month or so and then
deciding to mention it)! Problems are bound to occur and we have developed a procedure to
keep the paper trail straight but to a minimum. Save the original packing materials if you have
received a damaged shipment as it will help with the return or freight claim. (You will, however,
be expected to carry your return to Building 32 for shipment.) Appendix III is a reference guide
for placing purchase orders.
APPENDIX III
MIT BILLING AND SHIPPING INFORMATION

For placing purchase orders, please tell the vendor the following:

**Billing Address** (Bill to):
MIT
P.O. Box 9169
Cambridge, MA 02139-9169

**Receiving Address** (Ship to):
Your Name and Room Number* (if this is omitted, you’ll never see your order!)
MIT
Building 32 Shipping/Receiving
32 Vassar St.
Cambridge, MA 02139-4307

* If the item is very large (i.e. aluminum piping or computer equipment), have it delivered directly to 31-014 (Instrument Room)

** MIT has several receiving locations, so please be sure to specify the correct one for this lab.

**Shipping:**
Building 32 Shipping/Receiving
(All you need is a requisition)

If placing the purchase order by phone, tell the vendor they will be receiving a “confirming order” by FAX or PDF. (This will eliminate any chance of a duplicate order.)

After receiving the order, please return all packing slips and MIT truck slips to 31-264. Please feel free to make any copies of the above items for your files.

If you have any questions, don’t hesitate to ask Robin Courchesne-Sato, x3-2481.

If you received a damaged shipment, please see Robin.