Review of the Cushing Grammar

in the project seminar

Computational Natural Language Systems

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1 Introduction

The purpose of this work is to develop a correct and complete grammar for a substantial fragment of ATC/pilot communication as defined in e.g. the Aviation Information Manual [AIM] and the ATC Handbook [ATC]. Such a grammar was developed by Steven Cushing in Fatal Words [Cush1994] , however, we found it unsuitable for the purposes of the project of which this work is part.
The requirements for, and the grammar we developed is reported in [Hilb2001]. We report in this document the inadequacies we found in specific grammar rules in Cushings grammar.

2 The Cushing Grammar

2.1 The general idea of Cushing's grammar

The grammar was created by students in a research group at Boston University for the "Aviation Interface Research System" (AIR), an "Error-Resistant Visual Interface For Avitation Communication". The goal was to develop a visual communication system for two-way air-ground, pilot-controller communicaton. When a message is entered from an interface, a parser checks it for well-formedness before permitting it to another interface. The ATC grammar was needed for this parser. We found no indication as to how the grammar was created. There are several similarities to CVR transcripts and to the Aviation Information Manual [AIM]. The research group focused their work on the whole system. The grammar was only a small part of it. We will call it the "Cushing Grammar" in the rest of this document. We include the the original grammar as Appendix.

2.2 Necessity of a review

The Cushing Grammar was developed for a very specific task and system. There was no possibility to use the grammar without changing it for our purposes. We needed a grammar rigorously written in some standart form. The Cushing grammar doesn't fulfil this requirement. After an evaluation with a set of example phrases produced with the grammar and the study of the ATC handbook [ATC], the Aviation Information Manual [AIM] and transcripts of cockpit voice recordings we found several problems we had to solve before working with it. We detect these problems here.

2.3 The problems of the Cushing Grammar

In general there are two kinds of problems we found in the Cushing Grammar. Cushing created a very individual main form of grammar definition. And the syntax for which the grammar is built is not created according to a set of explicit rules. This ATC syntax includes many more problems than the form of the main syntax itself. The focus of our work was the development of the ATC syntax. The problems with the main syntax were relativly straight forward to solve.

- Main syntax
  To create a standard form of the grammar we decided to use a grammar in BNF [1] . There were many advantages to such a standart form (see [Hilb2001]).

  The Cushing Grammar is only in a "near-BNF" form. For alternative choice of values or phrases the signs "|" and "/" are alternately used. The non-BNF "/" has to be replaced by "|" and parentheses where necessary. To seperate alternative phrases the non-BNF sign "*or*" is used. Some rules are including semantic content by using a "*then*" to connect some phrases. In these cases we had recreated all non-BNF parts into the BNF. The example shows some of these aspects.

  Example 1: Use of the slashmark in a token definition

  <digit>   0/1/2/3/4/5/6/7/8/9

  Example 2: Use of semantic content in a phrase rule

  SQUAWK STANDBY.
  then,
  SQUAWK <code>.

- ATC syntax
  We checked the correctness of the grammar by checking the phrases the grammar is able to produce. We produced by hand 119 terminal strings using the 56 phrase-defining rules of Cushing's grammar. We made a detailed check of the sample phrases produced. Upon analysis of the terminal strings, more than 60% of them were found to be wrong. With the help of Peter Ladkin, a domain expert, the ATC Handbook [ATC] and the Aviation Information Manual [AIM] we found a lot of mistakes we allocate to the following criterias:

  – syntactically incorrect
    * orthography or punctuation is wrong
    * word order is wrong
    * incompleteness: necessary words/tokens are left out
    * superfluousness: a word/token is unnecessary at its position
  – semantically incorrect
    * wrong value, e. g. wrong interval of a number token
    * the phrase (or a part of it) makes no sense or will never be used
  – some words/tokens are informal speech or for military use only
  – syntactically and semantically correct

[1] Backus Naur Form, for a specification see for example [Schö1995]

Many parts of the grammar fulfil more than one of these criteria. So we didn't only classify each to the criteria. We tried to give a precise description of the problems we found in a short problem description. The critera description give a indication of the problems of the grammar. But with the problem description we were able to derive solutions for these problems. For example:

Example 3: incorrect token definition:

<heading> heading <digit++>

Problem: the non-terminal <digit++> generates ill formed strings like "heading 23405"

The Problem is, that the definition of the value with the non-terminal <digit++> is too general. The value of the heading can only be a value between 001 and 360 degrees. All other values are illegal. The problem of accurate token definitions is more complex than it may look . The legal values of tokens are not so easy to detect. A second problem is to decide where to define the correct values. Sometimes the value is used more than once and so you can define it as a seperate token. In other cases the value is only used once and can be used inside the token where it is needed. In the case of the heading value it makes sense to create a new token <degrees> because of the complexity of the definition of the value degrees. And because a specification of degrees is not only needed when giving a heading but also when giving a bearing for example.

The review of the token definitions and the legal phrases includes the short problem description. The problems of the main sytax are general and they are not marked in detail.

3 The review of the Cushing Grammar

The Cushing Grammar is divided into two main parts. There are the token definitions in the first part. The tokens describe the data used in air ground communication such as craft type, altitude or direction. These data definitions are used in the second part of the grammar. The "Legal ATC phrases" describe the syntax of the spoken phrases. There is a complex relation between the tokens and the phrases. Most of the problems cannot be solved only by looking either at the tokens or the phrases. Some tokens make sense stand alone, but in relation to a phrase rule a conflict appears, in respect to a second phrase rule it may have changed yet again, in a different way and in respect to a thrid phrase rule it may be correct.

3.1 Review of the token definitions

The review follows the criteria defined in section 2.3. A main problem of the Cushing Grammar is that many tokens which are used in the phrase definitions (and even in some token definitions itself) are not defined in the tokens section of the grammar. Tokens which are defined often have no values or their definitions are too vaguely indicated so that ill-formed strings can be generated or parsed. The notes (*Note: ...*) at some rules are original notes included by Cushing and describe some problems in detail. But they are not transferred into the definitions.

The incorrect token definitions and their problems are listed here:

<ffunction> (facility function)
Note: may not include all possible values

Problem: no values stated.

<lname> (location name)
Note: currently includes only a few cities

Problem: no values stated.

<clock-az> <digit++> O'CLOCK

Problem: the non-terminal <digit++> generates ill formed strings like "34 o'clock"

<miles> <digit++> MILES

Problem: the non-terminal <digit++> generates ill formed strings like "007055 miles" or "1 miles"

<rel-movement> CLOSING | CONVERGING | PARALLEL | OPPOSITE | DIVERGING | OVERTAKING | CROSSING (LEFT TO RIGHT | RIGHT TO LEFT)

Problem: OPPOSITE must be called OPPOSITE DIRECTION, some of the relative movement specifications are used before TRAFFIC and some after TRAFFIC.

<bird-species> DUCKS/GEESE/GULLS/SPARROWS

Problem: no need to specify the kind of birds.

<ltime> (local time indicator)
Note: currently includes only EST/MT/PST

Problem: will not be used and has incomplete values

<time> <digit++> (<ltime> | ZULU)
Note: <time> was simplified to make the interface dialogue easier to understand.

Problem: the non-terminal <digit++> generates ill formed strings like "34555 ZULU" or "645 MT", <ltime> will not be used.

<altimeter> ALTIMETER IS <digit++>

Problem: the non-terminal <digit++> generates ill formed strings like "altimeter is 23405"

<heading> HEADING <digit++>

Problem: the non-terminal <digit++> generates ill formed strings like "heading 2"

<frequency> <digit++> [(.<digit> [<digit>] | KHZ)]

Problem: the non-terminal <digit++> generates ill formed strings like "123.123", KHZ will not be used.

<speed> <digit++> KNOTS

Problem: the non-terminal <digit++> generates ill formed strings like "0815 knots" or "1 knots"

<altitude> *If the number of feet is less than 18,000:*
ALTITUDE <digit++> THOUSAND
[<digit> HUNDRED]
else:
FLIGHT LEVEL <digit++>

Problem: the "If . . . : . . . else:"-construct is not defined in (E)BNF and so it is unnecessary. The number contraints have to be checked by the grammar rule, thus <digit++> must be substituted by a more restrictive definition.

<fname> (facility name)
Note: currently includes only a few; for example, Logan

Problem: no values stated.

<craft-type> (type of aircraft)
Note: currently only DC-8 and APACHE defined

Problem: too few values stated, callsign is missing.

<route> VICTOR <digit++> [ROMEO | <location>],
or
J <digit++> [ROMEO],
<LMF-color> <digit++>,
or
NORTH AMERICAN ROUTE <digit++>,
or
(IR | VR) <digit++>.

Problem: the non-terminal <digit++> generates ill formed strings.

<LMF-color> (color of L/MF airway)
Note: currently only RED/BLUE

Problem: too few values stated.

<navaid> VOR/VOR-TAC/TACAN/RADIO BEACON

Problem: VOR-TAC, TACAN and RADIO are military navaid and so they can be left out for our purposes.

<fix> (<lname> <navaid> | <lname> (DME FIX | WAYPOINT | <radial> | <localizer> | <fix-azimuth>))
Note: definitions for radial, localizer, and fix-azimuth have not yet been provided, as there are too many unknowns

Problem: DME FIX and WAYPOINT should be non-terminals.

3.2 Review of the phrases definitions

The problems with the phrase rules are very specific for every rule. The general aspects are the disregard of the ATC syntax, sematic information which is difficult to use with a parser and misplaced token definitions. The notes (*Note:* ...) at some rules are original notes included by Cushing and describe some problems in detail. But they are not transferred into the definitions.

The incorrect phrase rules and their problems are listed here:

LOW ALTITUDE ALERT. CHECK YOUR ALTITUDE IMMEDIATELY. THE (((MEAM | MVA | MOCA | MIA) IN YOUR AREA) | MDA | DH) IS <altitude>.

Problem: MVA, DH will not be used, MEAM is called MEA, AREA is not used, use VICINITY instead.

CONTACT (<fname> | <lname>) <ffunction> [<frequency>] [AT (<time> | <fix> | <altitude)].

Problem: only a little misprint: the closing right angle bracket after "<altitude" is missing.

[<clock-az> | <direction>] TRAFFIC NO LONGER A FACTOR.

Problem: <direction> is unnecessary.

TRAFFIC, (<miles> | <digit++> MINUTES) <direction> OF (<fname> | <fix>), <direction>BOUND, [<craft-type>,] (<altitude> | ALTITUDE UNKNOWN). ESTIMATED <fix> <time>,
or
TRAFFIC, NUMEROUS TARGETS VICINITY (<fname> | <fix>).

Problem: <digit++> generates ill formed strings. New token <minute> must be added. "ESTIMATED <fix> <time>" will not be used here. It can be left out.

REQUEST FLIGHT CONDITIONS [OVER <fix> | ALONG PRESENT ROUTE |

BETWEEN <fix> AND <fix>].

Problem: "REQUEST FLIGHT CONDITIONS" will not be used alone. A specification is required. The specification "IN REGION" is missing and must be added.

(WEATHER/CHAFF) AREA BETWEEN <clock-az> AND <clock-az> <miles>.

or

<digit++> MILE BAND OF (WEATHER/CHAFF) FROM [<miles> <direction> OF] <fix> TO [<miles> <direction> OF] <fix>.

or

<weather-level> WEATHER ECHO BETWEEN <clock-az> AND <clock-az> <miles>, MOVING <direction> AT <digit++> KNOTS TOPS <altitude>.

or

DEVIATION APPROVED. ADVISE WHEN ABLE TO (RETURN TO COURSE | RESUME NORMAL NAVIGATION).

or

UNABLE DEVIATION. (FLY <heading> | PROCEED DIRECT TO <fix>).

Note: Deviation fragments are made more clear here. Official manual is ambiguous on this point.

Problem: CHAFF is for military purposes and can be left out here. <digit++> generates ill formed strings. use "<number> MILE" and "<number> KNOTS" instead.

WIND SHEAR (ALERT) | (ALERTS (TWO | SEVERAL | ALL) QUADRANTS). CENTERFIELD WIND <direction> AT <speed> (, <direction> BOUNDARY WIND <direction> AT <speed>) | (VARYING TO <direction> AT <speed>).

Problem: wrong parentheses, missing terminal REPORTED must be added.

CLEARED TO FLY <direction> OF <lname> <Navaid Type> BETWEEN THE <number> AND THE <number> (COURSES TO | BEARINGS FROM | RADIALS) WITHIN <number> MILE RADIUS.

Problem: the token <Navaid Type> is not defined. Change it to <navaid> which is defined. "COURSES TO" is unnecessary and can be left out.

or

CLEARED TO FLY <quadrant> QUADRANT OF <lname> <Navaid Type> WITHIN <number> MILE RADIUS.

Problem: the token <quadrant> is not defined. Change it to <quad> which is defined.

or

CLEARED TO FLY <direction> OF THE <lname> M-L-S RUNWAY <runway-num> BETWEEN THE <number> AND THE <number> AZIMUTHS WITHIN/BETWEEN <number> MILE RADIUS.

Problem: the token <runway-num> is not defined. M-L-S will not be used. The second BETWEEN makes no sense.

CLEARED DIRECT TO THE <fix> [, OFFSET <miles> RIGHT/LEFT OF <route>].

Note: CLEARED was added, and the fragment OFFSET was added to the fragment DIRECT. The DIRECT fragment was generalized to contain all valid fixes.

Problem: the word order is wrong. Change to "VIA <route> OFFSET ... ".

MAINTAIN/CRUISE ALTITUDE [UNTIL (<time> | PAST <fix> | <miles> PAST <fix> | <digit++> MINUTES PAST <fix>)].

Problem: <digit++> generates ill formed strings. Change it to <minutes> which must be defined. CRUISE must be an optional word after MAINTAIN, not instead of maintain.

[CLIMB/DESCEND AND] MAINTAIN <altitude> [(AFTER PASSING <fix>) | (AT <time>) | (WHEN ESTABLISHED AT LEAST (<miles> | <digit++> MINUTES) PAST <fix>)].

or

CLIMB/DESCEND TO REACH <altitude> [AT (<time> | <fix>)].

Note: AT <TIME> | <FIX> made optional in CLIMB TO REACH message.

Problem: <digit++> generates ill formed strings. Change it to <minutes> which must be defined. REACH is unnecessary.

MAINTAIN <altitude> THROUGH <altitude>.

Note: Referred to as <block altitude>.

Problem: the terminal BLOCK is missing and must be added. <altitude> generates wrong values here because flight levels will not be used here.

EXPECT CLIMB/DESCENT CLEARANCE (IN <miles> | IN <number> MINUTES | AT <fix>).

Problem: optional word FURTHER must be added. <number> is not defined. Use <minutes> instead which also must be defined.

REQUEST ALTITUDE CHANGE FROM <fname> [AT (<time> | <fix> | <altitude>)].

Problem: "ALTITUDE CHANGE" will not be used. The value <altitude> must be given instead. FROM is optional. REQUEST HIGHER/LOWER is missing.

CLEARED TO <fix>, HOLD <direction>, AS PUBLISHED.

Problem: incomplete sentence. "HOLD AT <fix>" must be added after HOLD.

or

CLEARED TO <fix>, NO DELAY EXPECTED.

EXPECT FURTHER CLEARANCE AT (<time> | <fix>) [ANTICIPATE ADDITIONAL <number> (MINUTE/HOUR)(DELAY AT <fix> | EN ROUTE DELAY | TERMINAL DELAY)].

Note: (time) was changed to AT <TIME> | <FIX>.

Problem: <number> is not defined. Use <minutes> and <hour> instead which also must be defined first.

CLEARED TO <fix>, HOLD <direction> OF <fix> ON THE (<number> RADIAL | <number> COURSE | <number> BEARING | <number> AZIMUTH | <route>)[, <number> MILE LEGS] [,LEFT/RIGHT TURNS].

Problem: <number> is not defined. Replace by precise tokens. First line is incomplete. Say: "HOLD AT <fix> . . . ".

| SHOW YOUR POSITION AS (PASSING <fix> | <miles> FROM <fix> | <miles> <direction> OF (<fix> | <lname>) | CROSSING/JOINING/DEPARTING <route> | INTERCEPTING/CROSSING <lname> <number> RADIAL).
Note: OVER/PASSING <FIX> was changed to PASSING <FIX> to avoid confusion with OVER that is used in parser to signify end of message (transmit). Also, note that | SHOW YOUR POSITION AS was added as a preface to make these into controller messages, where usually they are pilot responses to controller queries.

Problem: the first "|" is wrong.
Line 3 is incomplete. Say "...<route> AT <miles> FROM <fix>".

RADAR SERVICE TERMINATED.

Problem: "SQUAWK <code>" must be added as optional.

SQUAWK MAYDAY ON 7700.

Problem: "MAYDAY ON" is unnecessary.

RADAR CONTACT <fix>. IF FEASIBLE, SQUAWK <code>.
Note: <fix> was used above instead of (position).

Problem: "IF FEASIBLE, SQUAWK <code>" is not necessary. <fix> has to be replaced by <position>. <position> has to be optional.

RESET TRANSPONDER, SQUAWK <code>.

Problem: "SQUAWK <code>" is not necessary.

YOUR TRANSPONDER APPEARS INOPERATIVE, RESET, SQUAWK <code>.
Note: manual shows INOPERATIVE/MALFUNCTIONING

Problem: add MALFUNCTIONING.

STOP ALTITUDE SQUAWK. ALTITUDE DIFFERS BY <digit++> FEET.

Problem: the token <digit++> generates ill formed values.

AFFIRMATIVE <altitude>.
or
NEGATIVE. [CLIMB/DESCEND AND] MAINTAIN <altitude>.
Note: This phraseology was omitted from interface, because it requires a pilot-initiated dialogue, which has not yet been addressed. Also, AFFIRMATIVE/NEGATIVE could apply to any controller response to pilot-initiated queries.

Problem: AFFIRMATIVE and NEGATIVE are standalone words, that can be combined with a lot of other phrases. Create rules for that.

SQUAWK STANDBY.
then,
SQUAWK <code>.

Problem: the meaning of "then" is not included in (E)BNF. The rule can be put together with others into one rule.

RADAR CONTACT [<fix>].
Note: <fix> was used above instead of (position).

Problem: the phrase is already defined when changing <fix> to <position> as it is mentioned in the note.

THIS WILL BE A NO-GYRO VECTOR, TURN LEFT/RIGHT.
or
STOP TURN.

Problem: the phrase definition is incomplete. "START LEFT/RIGHT TURN" must be added.

FOR VECTOR TO (<fix> | <airway>).
or
FOR VECTOR TO INTERCEPT <lname> <number> RADIAL.
or
VECTOR FOR SPACING.
or
FOR VECTOR TO <lname> FINAL APPROACH COURSE.

Problem: The FOR is unnecessary in every phrase. A specification for <vector> is missing.

RESUME OWN NAVIGATION.
or
FLY <heading>. WHEN ABLE, PROCEED DIRECT <fix>.
Note: (position with respect to course/fix) removed from RESUME OWN NAVIGATION. Also, WHEN ABLE ... removed from FLY <HEADING> - it is implemented as part of DEVIATION messages.

Problem: the sentences are not used as alternatives. They must said one after another. <vector> must be used instead of <heading>.

(ACCELERATE | [IF PRACTICAL,] SLOW) TO (SPEED <speed> | (<mach-number>)
or
(INCREASE | [IF PRACTICAL,] REDUCE SPEED BY (<number> KNOTS | <mach-number>).
Note: Confusion among homonyms eliminated by revision.
SAY AIRSPEED.
or
MAINTAIN PRESENT SPEED.
or
DO NOT EXCEED <speed>.
Note: IF PRACTICAL, was added as an optional preface.

Problem: line 3: wrong parentheses, must be "...REDUCE) ...". Missing alternative "TO" to "BY". Line 5: alternative "MACH NUMBER" must be added.

(SLOW TO (SPEED <speed> | <mach number>) | REDUCE SPEED BY (<number> KNOTS | <mach number>)). THEN, DESCEND AND MAINTAIN <altitude>.
or
DESCEND AND MAINTAIN <altitude>. THEN, (SLOW TO (SPEED <speed> | <mach number>) | REDUCE SPEED BY (<number> KNOTS | <mach number>)).

Problem: the non-terminal "THEN" is not necessary.

CROSS <fix> AT (OR ABOVE/BELOW <altitude> | AND MAINTAIN (<altitude> | <block altitude>)) AT <speed>.
Note: The phrase above allows for all possible combinations of <speed> and <altitude> requirements for a CROSS <FIX> phrase.

Problem: two different phrases are mixed illegally. The separate phrases are already defined above.

4 Conclusions

4.1 Further Work

We created an ATC grammar fulfilling our concepts and including the results detected here (see [Hilb2001]). We proceeded as follows - First step is a decision as to where to locate a problem solution. There was sometimes the alternative to change a token definition or the phrase definition. We tried to separate the raw data in the token definitions from the phrases. We often needed to create new token definitions to solve relationship problems. We enlarged the token section by about 100%.

For these and the incorrect tokens definitions new values must be specified. This can be done by looking up which semantic entities the tokens stand for. There must be an analysis of the phrase rules where the tokens are used, so we could see the correct values in the explicit context. We also got hints for the syntax of the token definition from the ATC handbook [ATC] and the Aviation Information Manual [AIM], where we also found examples for data definitions and the syntax of ATC phrases.

Our way to develop the ATC grammar is surely not the only one. Nevertheless, many problems we uncovered must also be resolved by any attempt to devise a grammar conforming with common practice in machine parsing.

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[AIM] Aeronautical Information Manual
Official Guide to Basic Flight Information and ATC Procedures
`http://www.faa.gov/ATPubs/AIM/`

[ATC] Air Traffic Control
`http://www.faa.gov/ATPubs/ATC/`

[Airdis] Airdisaster.com
`http://www.airdisaster.com`

[ASN] Aviation Safety Network
`http://aviation-safety.net`

A The original Cushing Grammar

A.1 Syntax for Grammar Definition

The syntax used in the grammar specification given below is as follows:

- All uppercase letters indicate that the words are to be spoken verbatim.
- All lowercase letters enclosed in angle brackets indicate *tokens*, that is, variables whose syntax has been previously defined.
- Text in italics followed by a colon is used to specify conditions for alternative phrases.
- Brackets indicate that the enclosed data may or may not be applicable.
- Braces indicate that the enclosed data represent a description of what is to be said.
- Parentheses are used for grouping or to set off explanatory text (indicated by italics)
- A slash indicates that one of the two words the slash separates is to be selected.
- A vertical line, generally used in conjunction with parentheses, indicates that one of the two groups of words the vertical line separates is to be selected.
- An ampersand indicates that both words or phrases separated by the ampersand are to be used.
- When alternatives are provided for entire sentences, they are separated by an *or* indented on one line.
- A double plus sign indicates one or more repetitions of the preceding token; a plus sign followed by a number indicates that the preceding token should be repeated for a total of times equal to the given number.

A.2 AIR System Controller Grammar

The current grammar for the protocol language of the controller interface is as follows:

A.2.0.1 Token Definitions

<ffunction>	(facility function) *Note:* may not include all possible values
<lname>	(location name) *Note:* currently includes only a few cities
<clock-az>	<digit++> O'CLOCK
<direction>	<quad> | <location>
<quad>	NORTH | SOUTH | EAST | WEST
<location>	NORTHEAST | NORTHWEST | SOUTHEAST | SOUTHWEST

<miles> <digit++> MILES

<rel-movement> CLOSING | CONVERGING | PARALLEL | OPPOSITE | DIVERGING | OVERTAKING | CROSSING (LEFT TO RIGHT | RIGHT TO LEFT)

<bird-species> DUCKS/GEESE/GULLS/SPARROWS

<bird-size> SMALL/LARGE

<digit> 0/1/2/3/4/5/6/7/8/9

<ltime> (local time indicator)
Note: currently includes only EST/MT/PST

<time> <digit++> (<ltime> | ZULU)
Note: <time> was simplified to make the interface dialogue easier to understand.

<altimeter> ALTIMETER IS <digit++>

<heading> HEADING <digit++>

<frequency> <digit++> [(.<digit> [<digit>] | KHZ)]

<speed> <digit++> KNOTS

<mach number> MACH [1].<digit> [<digit>]

<altitude> *If the number of feet is less than 18,000:*
ALTITUDE <digit++> THOUSAND [<digit> HUNDRED]
else:
FLIGHT LEVEL <digit++>

<fname> (facility name)
Note: currently includes only a few; for example, Logan

<craft-type> (type of aircraft)
Note: currently only DC-8 and APACHE defined

<route> VICTOR <digit++> [ROMEO | <location>],
or
J <digit++> [ROMEO],
<LMF-color> <digit++>,
or
NORTH AMERICAN ROUTE <digit++>,
or
(IR | VR) <digit++>.

<LMF-color> (color of L/MF airway)
Note: currently only RED/BLUE

<navaid> VOR/VOR-TAC/TACAN/RADIO BEACON

<fix> (<lname> <navaid> | <lname> (DME FIX | WAYPOINT | <radial> | <localizer> | <fix-azimuth>))

Note: definitions for radial, localizer, and fix-azimuth have not yet been provided, as there are too many unknowns

<weather-level> (LEVEL 1 WEAK | LEVEL 2 MODERATE | LEVEL 3 INTENSE | LEVEL 4 | LEVEL 5 | LEVEL 6 EXTREME)

A.2.0.2 Legal Phrases in ATC Grammar

LOW ALTITUDE ALERT. CHECK YOUR ALTITUDE IMMEDIATELY. THE (((MEAM | MVA | MOCA | MIA) IN YOUR AREA) | MDA | DH) IS <altitude>.

TRAFFIC ALERT [<clock-az> | <direction>, <miles>, [<quad>BOUND], <rel-movement>]. ADVISE YOU [TURN LEFT/RIGHT [<heading>] AND] CLIMB/DESCEND [TO <altitude>] IMMEDIATELY.

CONTACT (<fname> | <lname>) <ffunction> [<frequency>] [AT (<time> | <fix> | <altitude)].

CHANGE TO MY FREQUENCY <frequency>.

REMAIN THIS FREQUENCY.

TRAFFIC, <clock-az> | <direction>, <miles>, [<quad>BOUND], <rel-movement>, [<craft-type>,] (<altitude> | ALTITUDE UNKNOWN).

[<clock-az> | <direction>] TRAFFIC NO LONGER A FACTOR.

TRAFFIC, (<miles> | <digit++> MINUTES) <direction> OF (<fname> | <fix>), <direction>BOUND, [<craft-type>,] (<altitude> | ALTITUDE UNKNOWN). ESTIMATED <fix> <time>,
or
TRAFFIC, NUMEROUS TARGETS VICINITY (<fname> | <fix>).

FLOCK OF (<bird-species> | [<bird-size>] BIRDS), <direction>BOUND ALONG <route> | <clock-az> <miles> <direction>BOUND | VICINITY (<fname> | <fix>)), (LAST REPORTED AT <altitude> | ALTITUDE UNKNOWN),
or
NUMEROUS FLOCKS (<bird-species> | [<bird-size>] BIRDS), VICINITY (<fname> | <fix>), (LAST REPORTED AT <altitude> | ALTITUDE UNKNOWN).

REQUEST FLIGHT CONDITIONS [OVER <fix> | ALONG PRESENT ROUTE | BETWEEN <fix> AND <fix>].

(WEATHER/CHAFF) AREA BETWEEN <clock-az> AND <clock-az> <miles>.
or
<digit++> MILE BAND OF (WEATHER/CHAFF) FROM [<miles> <direction> OF] <fix> TO [<miles> <direction> OF] <fix>.
or

<weather-level> WEATHER ECHO BETWEEN <clock-az> AND <clock-az> <miles>, MOVING <direction> AT <digit++> KNOTS TOPS <altitude>.

or

DEVIATION APPROVED. ADVISE WHEN ABLE TO (RETURN TO COURSE | RESUME NORMAL NAVIGATION).

or

UNABLE DEVIATION. (FLY <heading> | PROCEED DIRECT TO <fix>).

Note: Deviation fragments are made more clear here. Official manual is ambiguous on this point.

HOLD (SHORT OF RUNAWAY) | (IN POSITION).

Note: Terminal control messages are not part of current interface.

WIND SHEAR (ALERT) | (ALERTS (TWO | SEVERAL | ALL) QUADRANTS). CENTERFIELD WIND <direction> AT <speed> (, <direction> BOUNDARY WIND <direction> AT <speed>) | (VARYING TO <direction> AT <speed>).

CLEARED TO <fix> VIA ((<route> | <fix>)++).

Note: This message was used to group together all messages starting with VIA or involving route assignment.

CLEARED TO FLY <direction> OF <lname> <Navaid Type> BETWEEN THE <number> AND THE <number> (COURSES TO | BEARINGS FROM | RADIALS) WITHIN <number> MILE RADIUS.

or

CLEARED TO FLY <quadrant> QUADRANT OF <lname> <Navaid Type> WITHIN <number> MILE RADIUS.

or

CLEARED TO FLY <direction> OF THE <lname> M-L-S RUNWAY <runway-num> BETWEEN THE <number> AND THE <number> AZIMUTHS WITHIN/BETWEEN <number> MILE RADIUS.

CLEARED DIRECT TO THE <fix> [, OFFSET <miles> RIGHT/LEFT OF <route>].

Note: CLEARED was added, and the fragment OFFSET was added to the fragment DIRECT. The DIRECT fragment was generalized to contain all valid fixes.

MAINTAIN/CRUISE ALTITUDE [UNTIL (<time> | PAST <fix> | <miles> PAST <fix> | <digit++> MINUTES PAST <fix>)].

[CLIMB/DESCEND AND] MAINTAIN <altitude> [(AFTER PASSING <fix>) | (AT <time>) | (WHEN ESTABLISHED AT LEAST (<miles> | <digit++> MINUTES) PAST <fix>)].

or

CLIMB/DESCEND TO REACH <altitude> [AT (<time> | <fix>)].

Note: AT <TIME> | <FIX> made optional in CLIMB TO REACH message.

CROSS <fix> AT ((<OR ABOVE/BELOW <altitude>) | (AND MAINTAIN <altitude>)).

Note: The phrase above allows all possible combinations of <altitude> requirements in a CROSS <FIX> phrase.

CLIMB/DESCEND AT PILOT'S DISCRETION.

Note: AT PILOT'S DISCRETION was implemented as an option.

MAINTAIN <altitude> THROUGH <altitude>.

Note: Referred to as <block altitude>.

EXPECT CLIMB/DESCENT CLEARANCE (IN <miles> | IN <number> MINUTES | AT <fix>).

REQUEST ALTITUDE CHANGE FROM <fname> [AT (<time> | <fix> | <altitude>)].

EXPECT FURTHER CLEARANCE VIA ((<fix> | <route>)++).

Note: (routing) was assumed to refer to any combination of routes and fixes used to describe a clearance.

CLEARED TO <fix>, HOLD <direction>, AS PUBLISHED.

or

CLEARED TO <fix>, NO DELAY EXPECTED.

EXPECT FURTHER CLEARANCE AT (<time> | <fix>) [ANTICIPATE ADDITIONAL <number> (MINUTE/HOUR)(DELAY AT <fix> | EN ROUTE DELAY | TERMINAL DELAY)].

Note: (time) was changed to AT <TIME> | <FIX>.

DELAY INDEFINITE, EXPECT FURTHER CLEARANCE <time>.

Note: DELAY INDEFINITE was made an optional preface to all EXPECT messages.

CLEARED TO <fix> VIA LAST ROUTING CLEARED.

CLEARED TO <fix>, HOLD <direction> OF <fix> ON THE (<number> RADIAL | <number> COURSE | <number> BEARING | <number> AZIMUTH | <route>)[, <number> MILE LEGS] [,LEFT/RIGHT TURNS].

PRIMARY RADAR OUT OF SERVICE. TRAFFIC ADVISORIES AVAILABLE ON TRANSPONDER AIRCRAFT ONLY.

| SHOW YOUR POSITION AS (PASSING <fix> | <miles> FROM <fix> | <miles> <direction> OF (<fix> | <lname>) | CROSSING/JOINING/DEPARTING <route> | INTERCEPTING/CROSSING <lname> <number> RADIAL).

Note: OVER/PASSING <FIX> was changed to PASSING <FIX> to avoid confusion with OVER that is used in parser to signify end of message (transmit). Also, note that | SHOW YOUR POSITION AS was added as a preface to make these into controller messages, where usually they are pilot responses to controller queries.

RADAR SERVICE TERMINATED.

SQUAWK MAYDAY ON 7700.

RADAR CONTACT <fix>. IF FEASIBLE, SQUAWK <code>.
  Note: <fix> was used above instead of (position).

SQUAWK STANDBY.

RESET TRANSPONDER, SQUAWK <code>.

YOUR TRANSPONDER APPEARS INOPERATIVE, RESET, SQUAWK <code>.
  Note: manual shows INOPERATIVE/MALFUNCTIONING

SAY ALTITUDE.

VERIFY ALTITUDE AND ALTIMETER SETTING.

STOP ALTITUDE SQUAWK. ALTITUDE DIFFERS BY <digit++> FEET.

VERIFY AT <altitude>.
  or
  VERIFY ASSIGNED ALTITUDE <altitude>.

AFFIRMATIVE <altitude>.
  or
  NEGATIVE. [CLIMB/DESCEND AND] MAINTAIN <altitude>.
  Note: This phraseology was omitted from interface, because it requires a pilot-initiated dialogue, which has not yet been addressed. Also, AFFIRMATIVE/NEGATIVE could apply to any controller response to pilot-initiated queries.

SQUAWK ALTITUDE.
  or
  STOP ALTITUDE SQUAWK.

STOP SQUAWK.

SQUAWK <code> [AND IDENT].

SQUAWK STANDBY.
  then,
  SQUAWK <code>.

RADAR CONTACT [<fix>].
  Note: <fix> was used above instead of (position).

RADAR CONTACT LOST.
  Note: syntax for (alternative instructions when required) was not known, so it was omitted in the grammar fragment above.

TURN LEFT/RIGHT <heading>.
  or
  FLY <heading>.
  or
  FLY PRESENT HEADING.
  or
  DEPART <fix> <heading>.
  Note: FLY <heading> and FLY PRESENT HEADING were implemented as a choice at the end of a VECTOR phraseology.

TURN <degrees> DEGREES LEFT/RIGHT.

THIS WILL BE A NO-GYRO VECTOR, TURN LEFT/RIGHT.

or

STOP TURN.

FOR VECTOR TO (<fix> | <airway>).

or

FOR VECTOR TO INTERCEPT <lname> <number> RADIAL.

or

VECTOR FOR SPACING.

or

FOR VECTOR TO <lname> FINAL APPROACH COURSE.

RESUME OWN NAVIGATION.

or

FLY <heading>. WHEN ABLE, PROCEED DIRECT <fix>.

Note: (position with respect to course/fix) removed from RESUME OWN NAVIGATION. Also, WHEN ABLE ... removed from FLY <HEADING> - it is implemented as part of DEVIATION messages.

(ACCELERATE | [IF PRACTICAL,] SLOW) TO (SPEED <speed> | (<mach-number>)

or

(INCREASE | [IF PRACTICAL,] REDUCE SPEED BY (<number> KNOTS | <mach-number>).

Note: Confusion among homonyms eliminated by revision.

SAY AIRSPEED.

or

MAINTAIN PRESENT SPEED.

or

DO NOT EXCEED <speed>.

Note: IF PRACTICAL, was added as an optional preface.

(SLOW TO (SPEED <speed> | <mach number>) | REDUCE SPEED BY (<number> KNOTS | <mach number>)). THEN, DESCEND AND MAINTAIN <altitude>.

or

DESCEND AND MAINTAIN <altitude>. THEN, (SLOW TO (SPEED <speed> | <mach number>) | REDUCE SPEED BY (<number> KNOTS | <mach number>)).

CROSS <fix> AT (OR ABOVE/BELOW <altitude> | AND MAINTAIN (<altitude> | <block altitude>)) AT <speed>.

Note: The phrase above allows for all possible combinations of <speed> and <altitude> requirements for a CROSS <FIX> phrase.

RESUME NORMAL SPEED.

A.3 Phrase Examples

We created these examples with the phrase rules of the Cushing Grammar. This was the first step of reviewing it.

1. Low altitude alert. Check your altitude immediately. The MEAM in your area is flight level zero two five.
   Low altitude alert. Check your altitude immediately. The MDH is altitude one four thousand three hundred.

2. Traffic alert. Advise you turn left heading zero five five and climb to flight level four seven immediately.
   Traffic alert seven six o'clock. Advise you descend immediately.
   Traffic alert southeast, two miles, opposite. Advice you turn right heading
   zero nina zero and descend to altitude zero thousand immediately.

3. Contact Boston <ffunction> at Chicago marker.
   Contact Boston <ffunction> five four at Chicago waypoint.
   Contact Boston <ffunction> zero two five dot four three.
   Contact Boston <ffunction> zero two five kilo Hertz at seven Zulu

4. Change to my frequency zero four.
   Change to my frequency five dot three two.
   Change to my frequency six kilo Hertz.

5. Traffic, seven o'clock.
   Traffic, west, four three miles, crossing left to right, Apache, altitude unknown.
   Traffic, northeast, zero four five six miles, west bound, overtaking, flight level zero two five.
   Nina seven o'clock traffic no longer a factor.
   East traffic no longer a factor.

6. Traffic, seven five miles west of Chicago zero four five, southwest bound, DC-8, altitude unknown. Estimated Boston DME fix one eight Zulu.
   Traffic, five three minutes southwest of Logan, east bound, altitude one eight thousand. Estimated Boston two two five, five Zulu.
   Traffic, numerous targets vicinity Chicago beacon.

7. Flock of ducks, west bound along J seven five Romeo, blue four five, altitude unknown.
   Flock of canaries, zero four five o'clock one zero southwest bound, last reported at flight level seven five six.
   Flock of large birds, vicinity Boston waypoint, last reported at altitude two thousand one hundred.
   Numerous flocks of geese, vicinity Logan, altitude unknown.

8. Request flight conditions.
   Request flight conditions over Boston VOR.
   Request flight conditions along present route.
   Request flight conditions between Boston VOR and Boston marker.

9. Weather area between four three o'clock and five o'clock two miles.
   Four three two five mile band of chaff from two miles east of Boston waypoint to Chicago

three two five.
Level three intense weather echo between seven six o'clock and four five o'clock seven four miles, moving east at four four five knots tops flight level two.
Deviation approved. Advise when able to return to course.
Deviation approved. Advise when able to resume normal speed.
Unable deviation. Fly heading zero six zero.
Unable deviation. Proceed direct to Boston beacon.

10. Wind shear alert. Centerfield wind east at four seven one one knots, varying to northwest at zero knots.
    Wind shear alerts several quadrants. Centerfield wind southeast at five knots, northeast boundary wind north at one five knots.

11. Cleared to Boston three six zero via Victor seven four five northeast North American route four five
    Chicago zero eight five.
    Cleared to Boston DME fix via IR zero eight one five.

12. Cleared to fly east of Boston beacon between the four zero five and the eight zero bearings from within ten mile radius.
    Cleared to fly north quadrant of Chicago marker within zero eight mile radius.

13. Cleared to fly west of the New York M-L-S runway twelve between the twenty and the two zero azimuths between six mile radius.

14. Cleared direct to the Boston waypoint, offset zero two miles right of Victor three one northwest.

15. Maintain altitude two one miles past Boston marker.
    Maintain altitude until two pst.
    Maintain altitude zwo five minutes past Boston marker.

16. Climb and maintain fight level zero three five.
    Descend and maintain altitude three thousand five hundred after passing Boston marker.
    Climb to reach flight level zero four seven at seven three five zulu.

17. Cross Boston vor at flight level zero two six.
    Cross Boston vor and maintain fight level zero two six.

18. Climb at pilot's discretion.

19. Maintain flight level zero two through four thousand five hundred.

20. Expect climb clearance in one five zero miles.
    Expect descent clearance at Boston marker.
    Expect descent clearance in five minutes.

21. Request altitude change from Logan.
    Request altitude change from Logan at four thousand five hundred.
    Request altitude change from Logan at Boston marker.

22. Expect further clearance via Chicago VOR Victor five seven southwest.
    Expect further clearance via Victor five seven southwest Chicago VOR.

23. Cleared to Boston marker, hold west, as published.
    Cleared to Boston beacon, no delay expected.

24. Expect further clearance at Boston waypoint. anticipate additional two minute delay at Boston waypoint.
    Expect further clearance at Boston waypoint. anticipate additional two minute en route delay.
    Expect further clearance at Boston waypoint. anticipate additional two minute terminal delay.

25. Delay indefinite, expect further clearance one four Zulu.

26. Cleared to Boston VOR via last routing cleared.

27. Cleared to Boston marker, hold west of Chicago beacon on the five radial.
    Cleared to Boston marker, hold west of Chicago beacon on the ten bearing, left turns.
    Cleared to Boston marker, hold west of Chicago VOR on the Victor four three southeast, eight mile legs.

28. Primary radar out of service. Traffic advisories available on transponder aircraft only.

29. Show your position as passing Boston marker.
    Show your position as crossing victor seven nine zwo.
    Show your position as intercepting Boston seven radial.
    Show your position as zero eight one miles north of Boston marker.

30. Radar service terminated.

31. Squawk mayday on seven seven zero zero.

32. Radar contact Chicago beacon. If feasible, squawk seven seven zero zero.

33. Squawk standby.

34. Reset transponder, squawk five four seven six.

35. Your transponder appears inoperative, reset, squawk five four zero three.

36. Say altitude.

37. Verify altitude and altimeter setting.

38. Stop altitude squawk. Altitude differs by two zero zero feet.

39. Verify at flight level zero five seven.
    Verify assigned altitude flight level zero five seven.

40. Affirmative fight level one two three.
    Negative. Maintain flight level one two three.
    Negative. Climb and maintain flight level one two three.

41. Squawk altitude.
    Stop squawk altitude.

42. Stop squawk.

43. Squawk six seven one two.
44. Squawk standby.
    Squawk zero six five seven.
45. Radar contact Chicago waypoint.
46. Radar contact lost.
47. Turn left heading zero five six.
    Fly heading zero five six.
    Depart Chicago marker heading zero five six.
48. Turn zero two zero degrees left.
49. This will be a no-gyro vector, turn left. Stop turn.
50. For vector to Chicago marker.
    For vector to intercept Chicago three radial.
    For vector to Chicago final approach course.
51. Resume own navigation. Fly heading zero five eight. When able, proceed direct Chicago marker.
52. Accelerate to speed one zero zero Knots.
    Slow to mach dot four.
    Increase five knots.
53. Slow to speed one two zero Knots. then, descend and maintain flight level zero two one.
    Reduce Speed by zero one five Knots. then, descend and maintain flight level zero two one.
    Descend and maintain flight level zero two one. Then slow to speed one two three Knots.
54. Cross Chicago Marker at flight level zero four three at one three zero Knots.
    Cross Chicago Marker and maintain flight level zero two one at one three zero Knots.
55. Resume normal speed.