Find 40,000 new flute fingerings!

How would you like to be able to look up every single possible fingering for every single possible note on the flute? And what about every multiphonic for the standard C flute? Well, now you can do this and more, by visiting The Virtual Boehm Flute, a new website with literally thousands of fingerings generated by a combination of scientists, musicians and machines!

Pictures this. You’re sitting in an orchestra – you’re rehearsing for a concert next week. One of your solos has a trill from high F to high A, which you can’t seem to play quickly and elegantly. You’re using the trill fingering that you found in a good book on flute fingerings, but you still don’t feel you can play the solo to the standard that you would like.

What you need is a place where you can search for the trill in question and find new fingerings to try. Well, The Virtual Flute offers this and more. If you were to search on The Virtual Flute website for a trill between the two notes mentioned above, you would have this fingering returned for the F:

Th 1 2 3 I L - tr2 D#

If you try trilling between the A and this new F, you should be hugely surprised by the ease of playing and the clarity of the trill.

The Virtual Flute is online, so it’s free to all and is being visited by flute players all around the world.

What is it?
The Virtual Boehm Flute (its full name), is a website, launched in 2002, for flautists and composers. It gives access to an immense database of fingerings for the flute – C foot or B foot, with or without a split E. The reason it is so big is because it includes every fingering possible, for any note, and every multiphonic that is possible on the standard C flute. Three things can be done on The Virtual Flute:

● You can enter a fingering and find out every note that the fingering will produce. (This is mainly useful for checking or for understanding why a fingering is giving you problems.)
● You can look up any note and find every fingering that will play that note, ranked either by intonation or by ease of playing.
● You can find out whether a certain multiphonic is actually possible on the flute. If it is, you’ll be given a list of possible fingerings.

Why is it so complete? The Virtual Flute is the powerful result of combined forces; it has had input from musicians, scientists, engineers – and a computer program.

How does it work?
Excellent reference books and websites on alternative flute fingerings and multiphonics are widely in use and are generally collections of fingerings used by experienced flute players. The Virtual Flute is different from these in that it is not a collection of fingerings used by flute players. It is a database of almost 40,000 fingerings – the output of a computer-generated acoustic model of the flute. In other words, The Virtual Flute’s computer engineer wrote a program to simulate what happens, acoustically (inside the flute), when a flautist plays a note. The result is a comprehensive database of fingerings – it is a database of what it is physically possible for the flute to produce.

How do you use it?
Upon entering The Virtual Flute website, you will find three options; each has a different use.

1. To search for all the notes and multiphonics that a particular fingering will produce. You click on the keys of a diagram of a flute to specify the fingering, then click SEARCH. The result is a list of notes, ranked by their ease of production – three stars for easy, one star for very difficult. The tuning of each note is described – though this of course will vary when you play the note, depending on factors such...
The Virtual Boehm Flute
Choose from any of the three tools below...

1. Click the keys of a fingering to search for all its predicted notes and multiphonics...

   Allow unconventional finger positions
   - Split E
   - B Foot
   - C Foot
   - Both

2. Select a note from the list to search for an alternate fingering or microtone...

   e.g. AA, C6. Use standard note names: F#5 and G#5

   SELECT NOTE

   B Foot
   - C Foot
   - Both
   - Split E
   - No split E
   - Both
   - Allow unconventional finger positions

   Further reduce the number of fingering's...

   Fingerings MUST include the keys...
   - B, Bb, or Th
   - G
   - F#
   - G#
   - C
   - B
   - C
   - F# or G#
   - B
   - Bb
   - C

   And must NOT include the keys...
   - B, Bb, or Th
   - G
   - F#
   - G#
   - C
   - B
   - C
   - F# or G#
   - B
   - Bb
   - C

   OR...
   - Include any keys

   OR...
   - Don't include any keys

3. Search for a multiphonic fingering...
   e.g. C5D5E. Use standard note names.

   Select two or possibly three different notes from any list below:

   SELECT NOTE 1
   - C
   - D
   - E
   - F#
   - G#
   - A
   - B

   SELECT NOTE 2
   - C
   - D
   - E
   - F#
   - G#
   - A
   - B

   SELECT NOTE 3
   - C
   - D
   - E
   - F#
   - G#
   - A
   - B

   OR...
   - B Foot
   - C Foot
   - Both
   - Split E
   - No split E
   - Both
   - Allow unconventional finger positions

   Further reduce the number of fingering's...

Figure 1. The main page of The Virtual Flute website.
as embouchure, temperature, the brand of flute that you are playing and various adjustments such as key openings and cork position.

2. To search for a fingering to play a particular note, you may be seeking:  
   A: An alternative fingering, for a trill or for a rapid passage, because the standard one is awkward (as in high F to high A, as mentioned above);  
   B: A microtonal pitch, which is useful not only for playing contemporary works with half sharps etc, but also if, for example, the standard fingering is tricky to play in tune on a difficult entry;  
   C: A particular timbre on the note. Searches will often produce hundreds of fingerings - even thousands for some notes. You can enter keys that you want to include in the fingering or keys that you definitely don't want to include (particularly for trills). This allows you to find just the fingerings that are relevant to your problem; you might, for instance, include the keys from the previous or following note. This narrows the search, lowering the number of results and making them easier to sift.

3. To search for a multiphonics of two or three notes.  
Many combinations of notes are simply unplayable on the flute, especially in the low range. However, in the third and fourth octaves, there are lots of possibilities.

With all three search options, you should select whether you have a B foot or C foot flute, and whether your flute has a split E mechanism or not. This enables the search to be specific to your flute. There is an option to select an unconventional finger position, making it possible to include in a search the keys that are not normally touched by a player, such as the key to the left of the right hand F key (from the perspective of the flutist). This is particularly useful when searching for multiphonics in search option 3 as it allows the search to return more possibilities.

The Virtual Flute is potentially useful to composers who may not necessarily be advanced flute players. It gives them online access to a tool for finding out if a particular multiphonics exists on the flute or if variations in timbre on a certain note are possible on the instrument.

**How was The Virtual Flute created?**

A flute with all the tone holes closed has a long column of air, enclosed in the middle but open at both ends. When someone blows into the flute, sound waves travel up and down the tube, producing a standing wave. The cards show the frequency of the notes and frequencies for all holes closed are shown on the left in Figure 2. These produce the notes C4 (middle C), C5 and G5.

The acoustic characteristics of a woodwind instrument may be quantified by measuring its acoustic impedance. This is a ratio of pressure to flow at the input to the instrument and describes how the instrument will respond to being blown. I like to think of impedance as 'a resistance to vibrate'. The acoustic impedance for a flute with all holes closed is much higher than the curve on the right in Figure 2. Impedance is plotted on the y-axis and frequency (pitch) on the x-axis. The curve has many maxima and minima. The minima correspond to the possible standing waves, and the notes the flute can play are very close in frequency to these minima.

| Acousticians measure the acoustic response of the flute for hundreds of fingerings | Flutist reports 'playability' for every resonance on these fingerings (957 resonances) |
| Make theoretical model for the response of the flute | Determine, using machine learning, which parameters of acoustic response are related to playability |
| Test model on measurements and then improve model | Calculate acoustic response spectrum, using the model, for all 39,744 fingerings |
| Construct expert system to determine playability from any given acoustic response | Analyse every acoustic response for notes, microtones and multiphonics possibilities; Create a database |
| Create a user-friendly 'front end' that allows musicians to interrogate the database in an intuitive way |

*Figure 3. Flute chart showing the scientific stages of The Virtual Flute being created in the acoustics laboratory.*
In recent years, the University of New South Wales Music Acoustics Laboratory has developed a technique to measure acoustic impedance with unrivalled clarity. This development allows accurate simulations to be built, forming the basis of The Virtual Flute.

For each possible fingering, of which there are almost 40,000, acoustic impedance was pre-simulated by a computer model of the instrument. This gave an impedance spectrum for each fingering—a graph of the impedance over all frequencies within the range of the flute. For 80 given fingerings, I manually examined the playable notes of each fingering and the ease of their production. The task of matching musical responses to the features of impedance spectra was then learned by a machine, which completed the job for the thousands of remaining fingerings. The Virtual Flute is the window to this vast quantity of machine-generated data, digitally infused with my own playing.

The impedance can also tell us about the tonal characteristics and playability of a note. If for a given fingering there are many impedance minima with frequencies in a harmonic relationship to each other, then the note produced will be harmonically rich (bright); if not, the note will be more pure (or dull sounding).

Examples of new fingerings
Here are a couple of new fingerings that I have found using The Virtual Flute:
- Stravinsky's Firebird requires an acciacattura from B5 (B above the stave) to E6 (the E above that) and back to B5. It's far too easy to split the last B and slip up to an F#6 instead.

The Virtual Flute, however, returned a great fingering for the E6 which alleviated the problem:

\[ \text{Th 1 2 - 1 1 - D# tr1 tr2} \]

- have you ever needed to play top F? (That's the F in the fourth octave.) If so, you'll have found it quite strenuous, or impossible, to play it piano. The Virtual Flute found the following fingering for flutes with a split E mechanism. It's not only extremely clear, it's also unproblematic to play softly!

\[ 1 2 - 1 - 2 - - - tr2 \]

Who was involved?
A couple of years before the launch of The Virtual Flute, a computer engineering student would often sit in the audience to listen to the University of New South Wales Orchestra. The following year, this student, Andrew Botros, would be undertaking his final year undergraduate thesis project. The topic of this project was then undecided.

I was a linguistics student and principal flautist with the orchestra at the time. I had been, for the past two years, sitting next to a researcher working in music acoustics, Joe Wolfe, on first oboe. He had earlier recruited me as 'Flautist in Residence' of The Acoustics Laboratory, consulting with the acoustic physicists on some musical aspects of their research.

Joe (the oboist) and Dr John Smith (a bass player in the same orchestra) had already been working on flute acoustics for a couple of years. During 2001, Andrew joined their team in the Acoustics Laboratory and built his computer system. His project was supervised by Joe, who, in addition to being a physicist, is a fine musician. I had a range of jobs on the project. One was to play a few hundred different note-finger combinations and rank their ease of playing. The results of this were the basis of the system that decides if a particular resonance on the flute is playable and, if so, how easily.

In 2002, The Virtual Flute was launched and has since won the prestigious Australian engineering award. The Siemens Prize for Innovation. The Virtual Flute has begun to make its mark in the worldwide flute community— it is currently visited hundreds of times each day.

Andrew later received the University Medal for his work and is currently a successful biomedical engineer, working with cochlear implants. Joe is a professor in the School of Physics at The University of New South Wales. He, colleague Dr John Smith, and engineer John Tann run one of the world's leading research groups in musical acoustics. (The lab has won many prizes recently including the Australian Acoustical Society Excellence in Acoustics Award.)

Want to know more?
- Visit The Virtual Flute! You'll find it at: www.phys.unsw.edu.au/music/flute/virtual
- Visit the Flute Acoustics page - a comprehensive resource for learning about the physics of flute playing: www.phys.unsw.edu.au/music/flute

Andrew Botros, who won The 2002 Siemens Prize for Innovation, with the author Jane.